UCRL-ID-131919

DSWA Calorimeter Bomb Experiments

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October 1, 1998

Lawrence Livermore National Laboratory

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Work performed under the auspices of the Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

August 24, 1998
Bruce Cunningham

DSWA Calorimeter Bomb Experiments

Summary of Work

Two experiments were performed in which 25 grams of TNT were detonated inside an expended detonation calorimeter bomb. The bomb had a contained volume of approximately 5.28 liters. In the first experiment, the bomb was charged with 3 atmospheres of nitrogen. In the second, it was charged with 2.58 atmospheres (23.1 psi gage) of oxygen. In each experiment pressure was monitored over a period of approximately 1200 microseconds after the pulse to the CDU. Monitoring was performed via two 10,000 psi 102A03 PCB high frequency pressure transducers mounted symmetrically in the lid of the calorimeter bomb. Conditioners used were PCB 482As. The signals from the transducers were recorded in digital format on a multi channel Tektronix scope. The sampling frequency was 10 Mhz (10 samples per microsecond). After a period of cooling following detonation, gas samples were taken and were subsequently submitted for analysis using gas mass spectrometry. Due to a late request for post shot measurement, it was only possible to make a rough estimate of the weight of debris (carbon) remaining in the calorimeter bomb following the second experiment.

Summary of Results

Principle results include two digitized traces from each experiment, plus two each (redundant) gas spectrometry reports from each experiment. Figures 1 and 2 in Appendix 1 show the two traces from each experiment in overlay. Results from the mass spectrometry analysis are included in Appendix 2.

A few general observations about the data are as follows:

In the nitrogen experiment, the output records from the two transducers are distinctly different during the initial 150 microseconds following arrival of the first pressure wave at the transducers. Thereafter, the traces appear to be in fairly good agreement, disregarding the short duration high pressure "spikes" which begin appearing at about 450 microseconds after the start of the CDU pulse.

In the oxygen data, the two traces are more alike during the initial portion of the pressure wave records than was the case with the nitrogen data. Thereafter they appear to be quite similar in form but are offset from one another by approximately 1000 psi.

Compared to the nitrogen experiment, the oxygen experiment traces show a good deal more wave activity. There are also many more "spikes" evident.

The redundant mass spectrometry measurements show good test-to-test consistency. A cursory comparison of the results to those reported by Don Ornellas on a similar shot in oxygen (see pages 76 & 77 of UCRL 52821) indicates a similarity in relative N_2 content but substantially more C0. It should be pointed out that differences between this experiment, and Don's experiment are several. In this experiment there was more oxygen present initially, there was a 1.6 gram LX10 booster used instead of PETN, and, importantly, there was no confinement. A lack of confinement results in reshock to high temperature at low pressure, resulting in carbon and CO_2 combining to yield CO (per conversation with Leroy Green).

Details Of The Experiments

1) Preparation

Appendix 3 contains a copy of the Peer Review written for these reported experiments. Referring to the SETUP slide contained in the Peer Review, the bomb was suspended by nylon rope attached to a wooden 2x4 placed across the top of the drum, not from a tripod as shown. Not shown or discussed in the Peer Review is a dual in-line filter system which was placed, for safety reasons, between the evacuation pump and the lines. In addition, a 10,000 psi gage was added to the high pressure side of the line (above the high pressure fitting on the lid). The purpose of the gage was to assure those entering the tank that the pressure inside the calorimeter had dropped to a low level, prior to sampling.

2) Notes on the Experiments

A sheet showing specific details on the charges is included in Appendix 4. The charges were suspended differently in the two shots. In the nitrogen experiment, the charge was suspended in a basket made from HE tape. The detonator was also held in place by tape. In the oxygen experiment, the charge was suspended in a stainless steel wire basket and the detonator was glued in place using a two part epoxy. In both cases, the baskets were hung from the bottom of the bomb lid using stainless steel wire.

Appendix 5 contains the factory calibration sheets for the four PCB gages used in the experiments (two new gages were used in each shot).

The vessel was extremely dirty due to the fact that it had been used a number of years ago and then allowed to sit, uncleaned for many years, following the experiment. This necessitated an extensive effort to try and clean the vessel. These efforts produced good, but not perfect, results. The vessel was well worn and heavily pitted inside. Due to extensive stretching in the bolt hole and pressure port threads it was necessary to retap all holes prior to use.

Assembly was as previously described. The transducers were mounted in the lid at a recess of about .080" and silicone grease was used to fill each cavity. Following, a square of black vinyl tape was placed over each hole. Photographs are included in Appendix 6. Care was taken in both experiments to insure that the charge was properly centered in the vessel (with the charge center located at the center of the sphere). However the level of care taken was greater in the second experiment than the first, following examination of the first shot results which suggested possible asymmetry in charge position or in detonation. A number of factors, including stiff CDU wires, made positioning difficult.

The recording system was tested prior to the experiments by firing bridgewires mounted first inside the closed vessel, and later outside. In this way it was discovered that the CDU was generating an enormous amount of noise (see Appendix 7) which clearly would have obscured the transducer signals. This problem was eventually fixed by ground strapping the vessel to the wall of the firing tank, and using an isolation transformer to which both 482A conditioners and the Tecktronix scopes were grounded.

In each experiment the bomb was twice evacuated and charged to one atmosphere with the appropriate gas. Then the vessel was evacuated a third time (to less than 50 milli-torr) and subsequently filled. In the first experiment the vessel was filled with 3 atmospheres abs. of nitrogen. The oxygen manifold system used in the second experiment would only allow for a fill to 2.58 atmospheres abs. and so this was the pressure at which the second experiment was conducted.

Thermocouples were used to monitor the temperature of the water in the drum. The intent had been to use water temperature as a means of assessing when the bomb had cooled. In fact, the increase in temperature was very small and the information proved unnecessary because the bomb cooled completely in less than an hour. The pressure gage mounted in the high pressure line attached to the bomb confirmed the fact that pressure in the bomb had dropped to a safe level.

Gas samples were taken by filling standard pre-evacuated .8 liter gas bottles provided by Chemistry. Samples were taken after first evacuating the connecting line between the bomb and the sample bottle. Redundant analysis were performed, as requested, and results were reported to three digits. Those performing the tests were unable to provide an estimate of the amount of H_2O present due to (reportedly) the presence of water vapor in their test lines which would have invalidated the results.

General Comments

There are a number of important questions about the data from these experiments. The first question is why the initial pressure data from gages 1 and 2 is initially so different, especially in the case of the nitrogen experiment. A possible explanation is that the charge was not well centered or that it did not initiate symmetrically. The signals in the oxygen experiment are somewhat more consistent, perhaps the result of a good deal more care taken to try to insure symmetry in the second shot. It should be noted that these experiments are quite different from experiments performed previously in the 1 kg tank where, because of the relatively large distances to the wall, the charge behaved like a point source.

A second question that arises is what is the source of "noise spikes" that appear in both data sets. Discussion with a number of people with experience in the field, including Leroy Green, Bill Shay, Dan Greenwood, as well as PCB technical support representatives, have yielded suggested explanations ranging from electrical noise to ringing in the vessel. In some cases the amplitudes are extremely large - far in excess of 24 volts. The gages are accelerometer compensated and the manufacturer quotes an output response to mechanical excitation of less than .002 psi/g acceleration. At an indicated pressure (saturation state on the scope) of 24000 psi, this would correspond to 12.5 million gs.

Included in Appendix 1 are detail traces of several of the "spikes" from both experiments. With the exception of the first detail trace from the second experiment, all waveforms appear to be sawtooth in form and are only a few microseconds in duration. The manufacturer suggests that the "noise spikes" might be the result of signal cable movement (possibly intermittent interruption at the connector). However there is doubt that enough time has passed to allow gross mechanical motion, such as cable whipping, to occur. However, there is plenty of time for longitudinal waves (or slower shear waves, for that matter) to reach the connector region of the transducer.

A final question is what is the source of what appears to be a fixed difference in indicated pressure between transducers one and two in the oxygen experiment. Note that in the second trace the indicated pressure drops to approximately -300 psi between the second and third main reflections which is clearly erroneous. The manufacturer (PCB) was sent the traces to examine. They believe that the difference is caused by thermal effects. This opinion is seconded by Bill Shay, a long time employee of the Laboratory and experienced user of PBC gages. It is known that these gages are indeed quite sensitive to thermal effects. Because the crystals are pre-loaded and their structure is such that heat causes a reduction in load, then exposure to elevated temperatures results in a reduction in signal level. There is doubt, though. as to whether there is sufficient time for gages to be effected by heat in this very short - approximately 100 microsecond - time frame.

Suggested Considerations For Future Work (In no particular order).

1) Consider using a two conductor terminal for firing the detonator, thus eliminating the need to ground directly to the containment vessel.

2) Consider fabricating a new test vessel with a completely spherical interior, Minimize protrusions.

3) Consider firing a spherical charge, initiated from the middle, to reduce complexities caused by inherent asymmetries associated with a cylindrical charge initiated from one end.

4) Consider devising the means to insure exact centering of the charge relative to containment vessel walls.

5) Consider employing noise reduction circuitry of the type typically used by Bill Shay (a two conductor twisted-pair from transducer to conditioner, shielded with a ground wire conductor running to a differential amplifier ground, and the differential amplifier placed in line between the conditioner and the scope.

6) Consider the use of a transducer which has been ceramic coated at its tip (like a PCB 109), or an optical transducer, to reduce possible thermal effects.

7) Consider use of damping media around the vessel or specifically around the transducer to attenuate and/or isolate the transducer from mechanical ringing.

8) Measure the output bias from transducers after the shot to determine whether a permanent shift may have taken place.

As a general approach, assessments should be made of the relative probabilities of the various suggested problem causes, after which experiments should be conducted to try and reproduce the effects observed.

Appendix 1

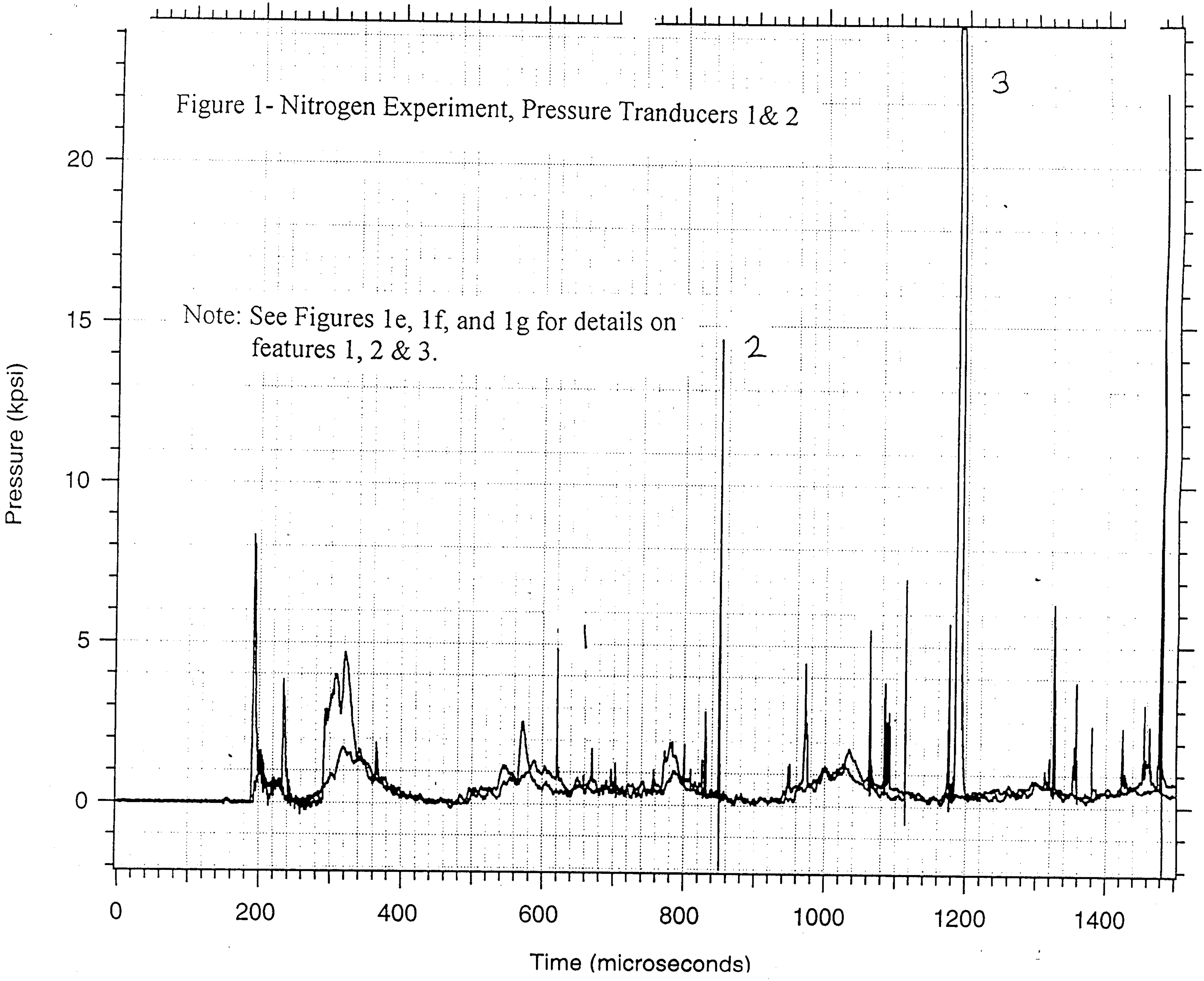
Figure 1- Nitrogen Experiment, Pressure Tranducers 1& 2
Note: See Figures 1e, 1f, and 1g for details on
features 1, 2 & 3.
1
2
3
Pressure (kpsi)
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
Time (microseconds)

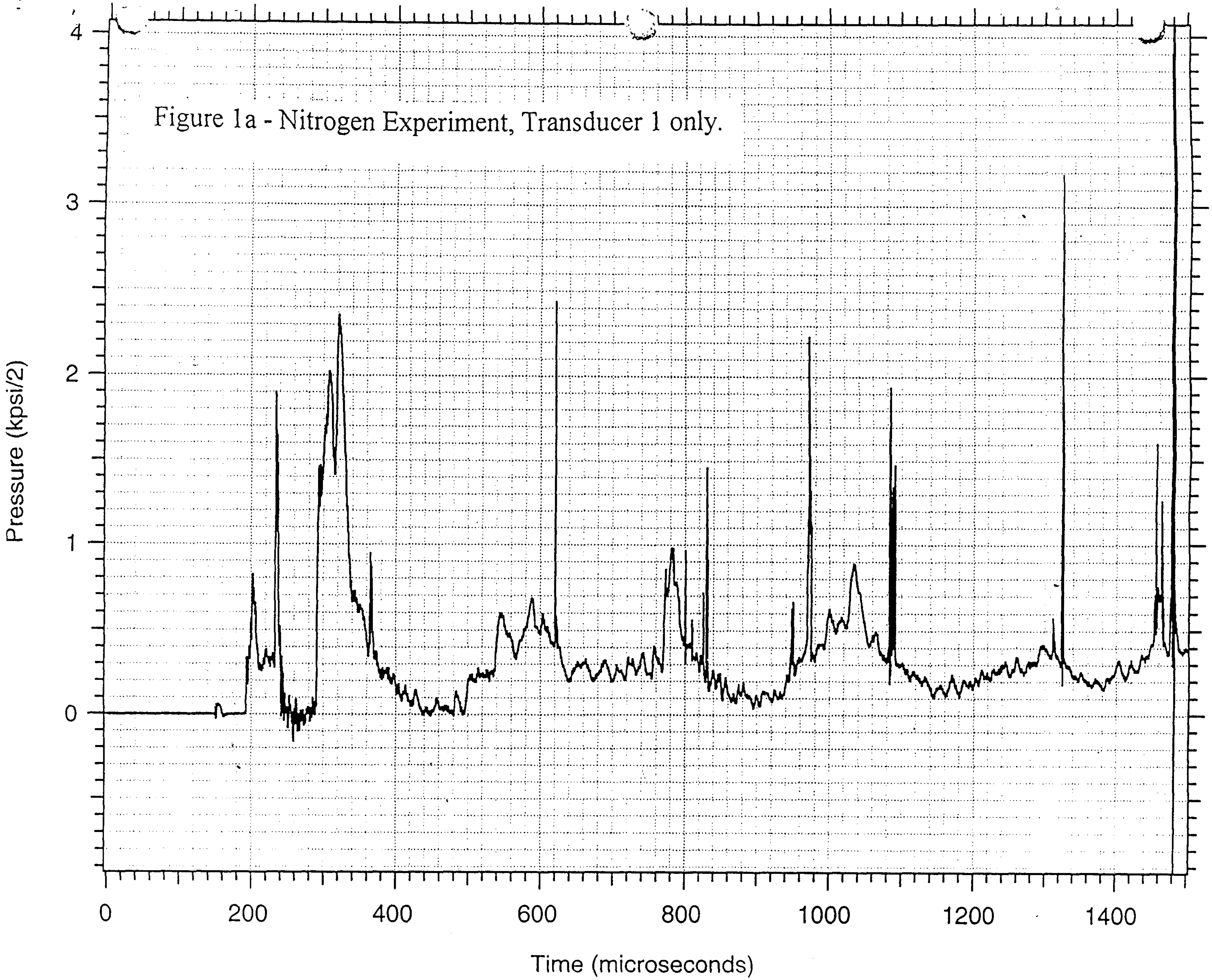

Figure 1a - Nitrogen Experiment, Transducer 1 only.
Pressure (kpsi/2)
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
Time (microseconds)

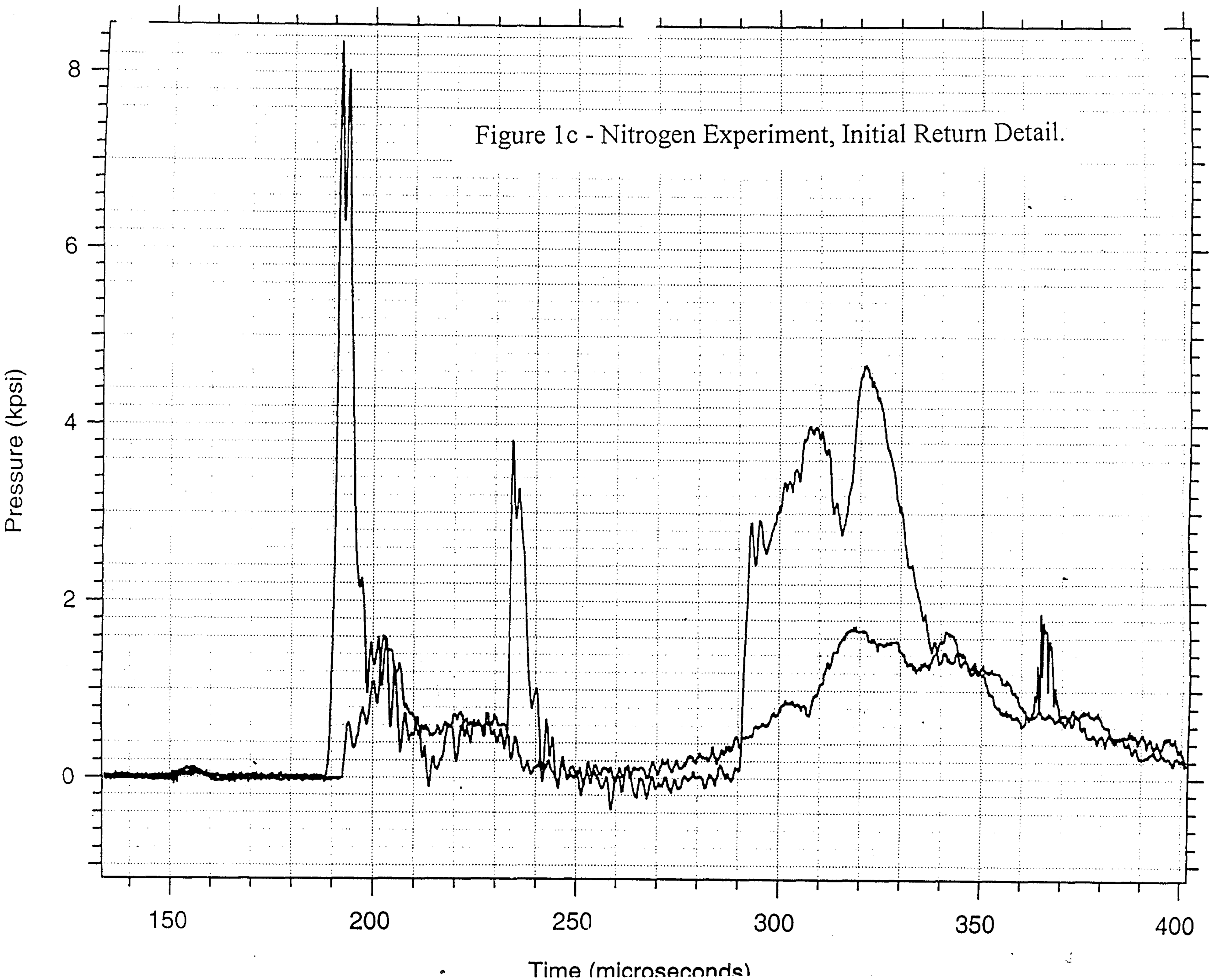
Figure 1c - Nitrogen Experiment, Initial Return Detail.
Pressure (kpsi)
8
6
4
2
0
150
200
250
300
350
400
Time (microseconds)

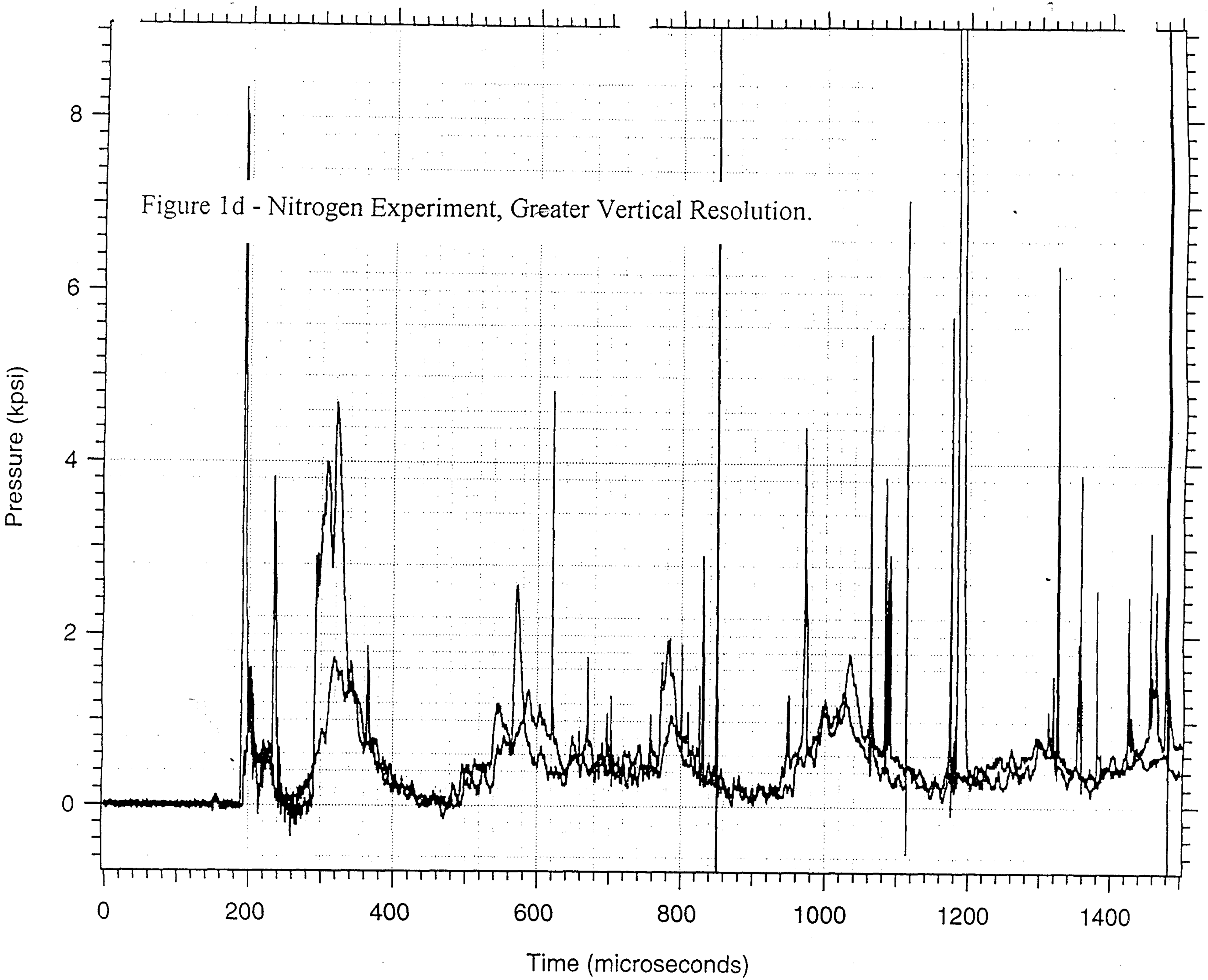

Figure 1d - Nitrogen Experiment, Greater Vertical Resolution.

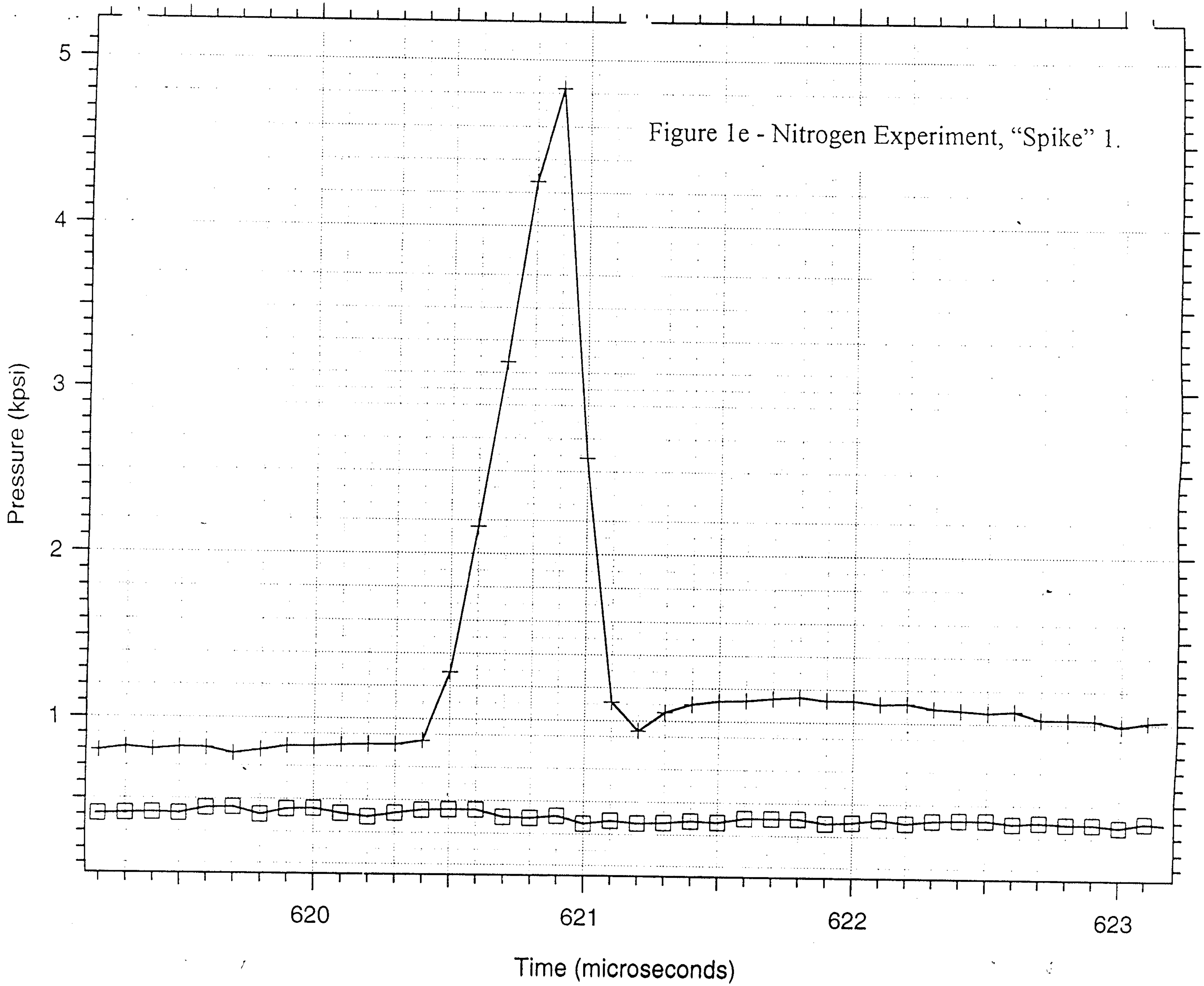
Figure 1e - Nitrogen Experiment, "Spike" 1.
Pressure (kpsi)
5
4
3
2
1
620
621
622
623
Time (microseconds)

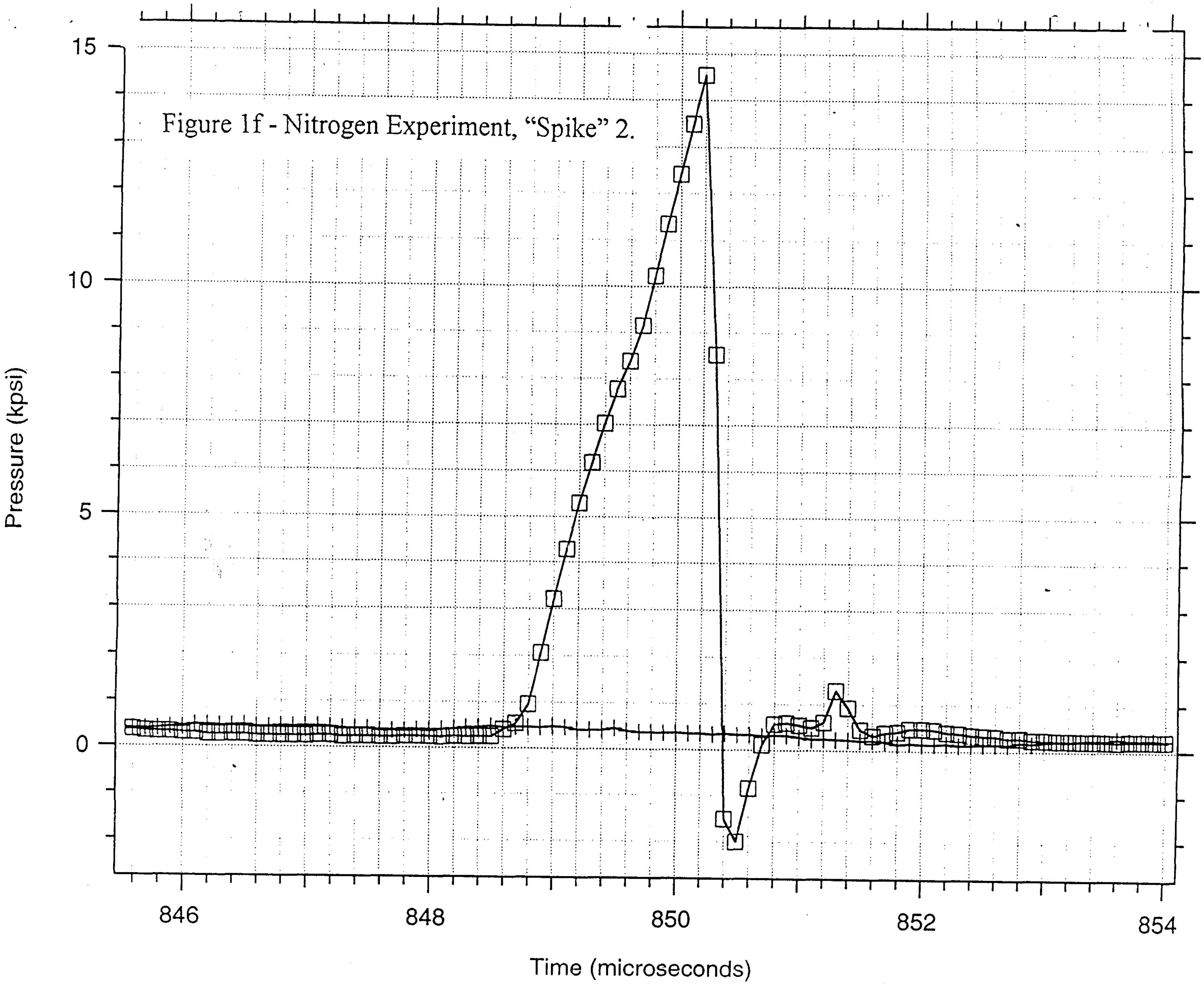
Figure 1f - Nitrogen Experiment, "Spike" 2.
15
10
5
0
Pressure (kpsi)
846
848
850
852
854
Time (microseconds)

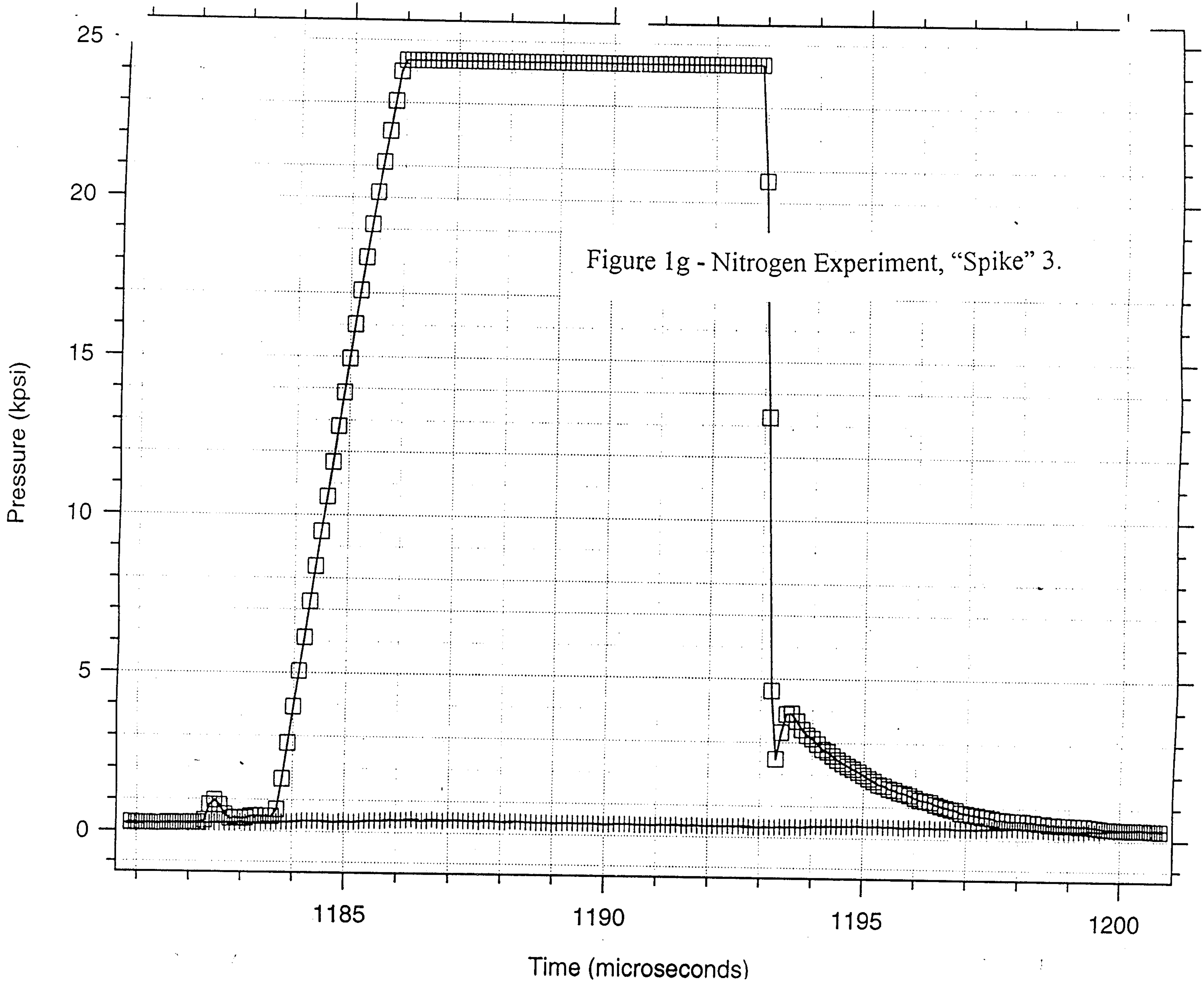

Figure 1g - Nitrogen Experiment, “Spike” 3.

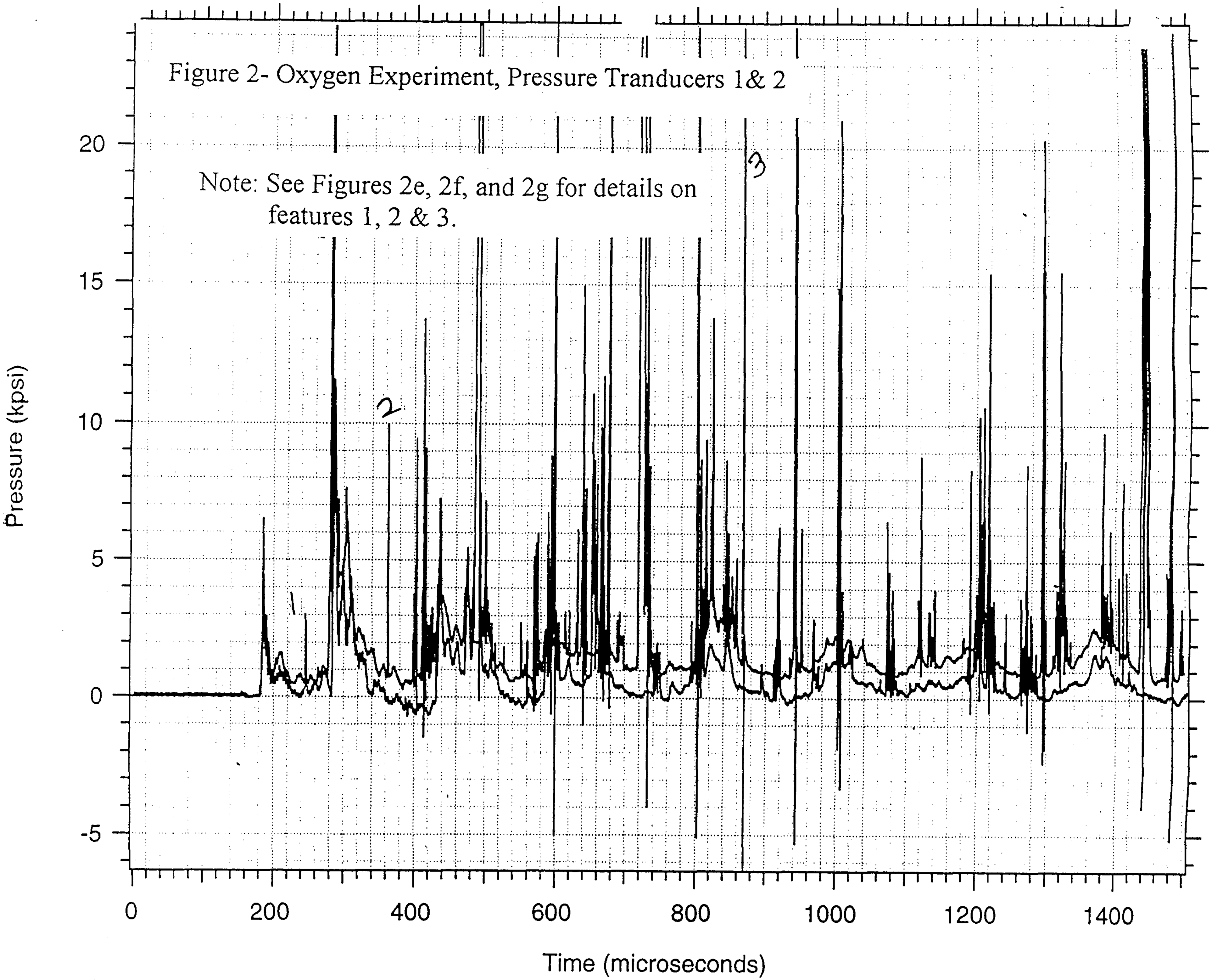
Figure 2- Oxygen Experiment, Pressure Tranducers 1& 2
Note: See Figures 2e, 2f, and 2g for details on features 1, 2 & 3.
Pressure (kpsi)
Time (microseconds)
20
15
10
5
0
-5
0
200
400
600
800
1000
1200
1400
1
2
3

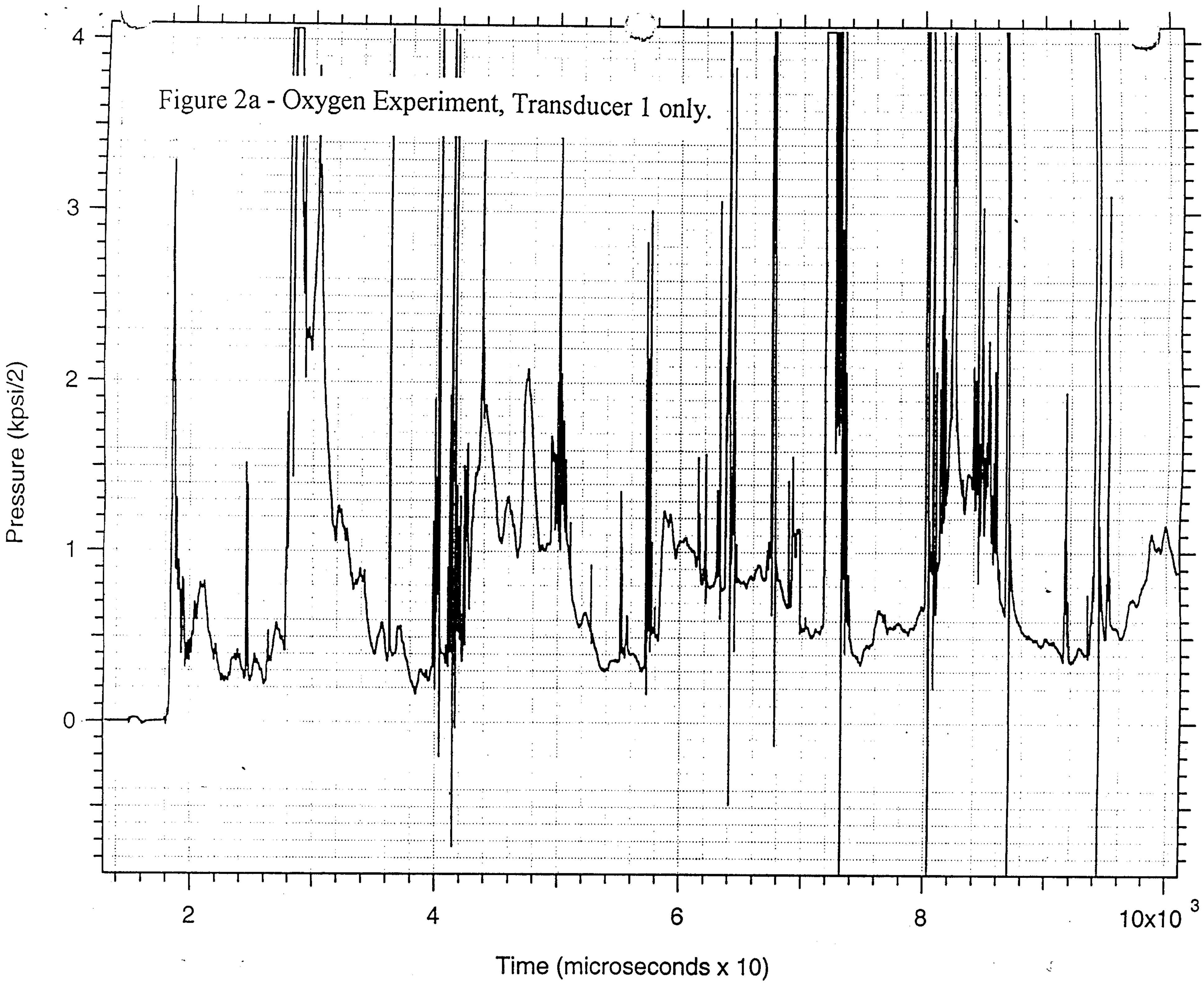

Figure 2a - Oxygen Experiment, Transducer 1 only.
Pressure (kpsi/2)
4
3
2
1
0
2
4
6
8
10x10 3
Time (microseconds x 10)

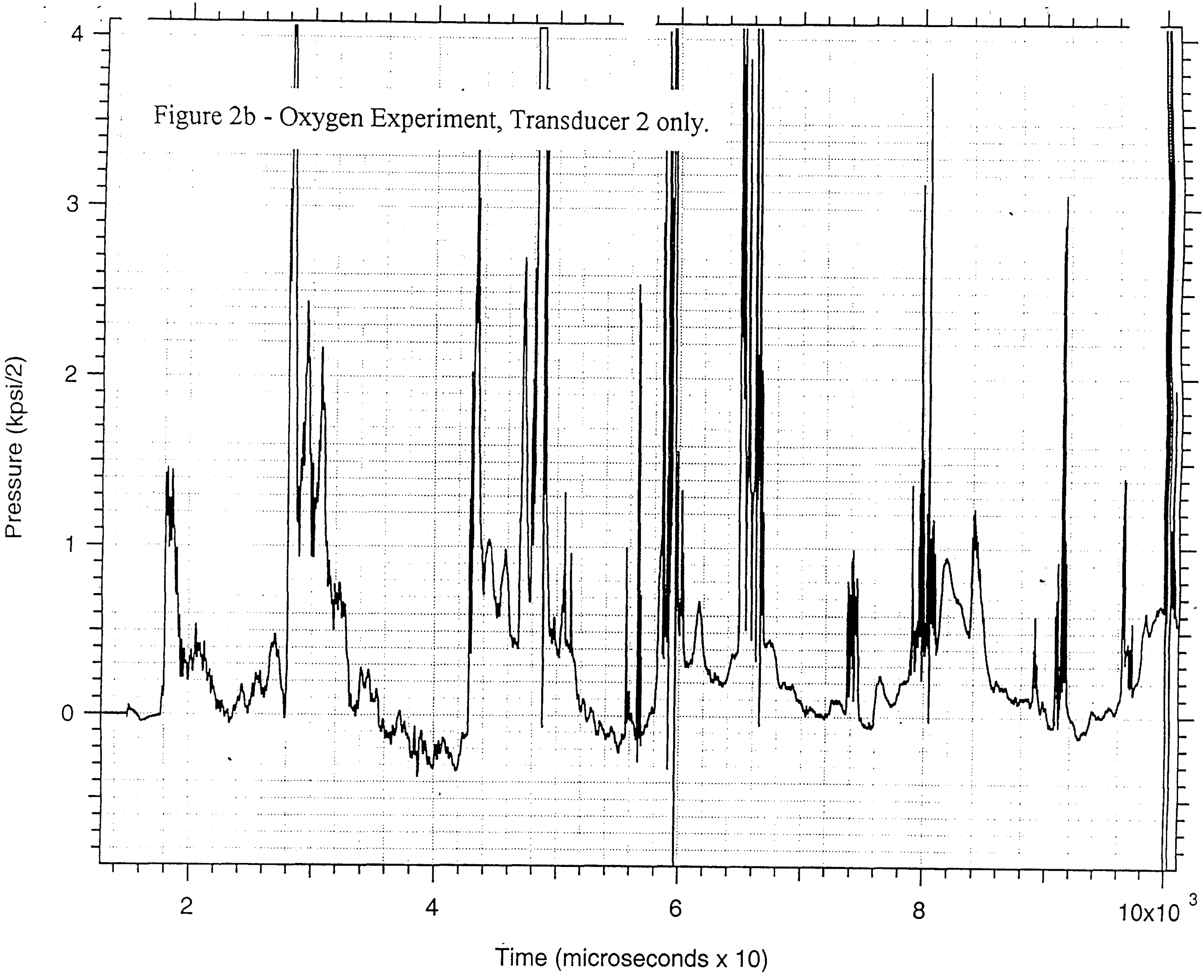

Figure 2b - Oxygen Experiment, Transducer 2 only.

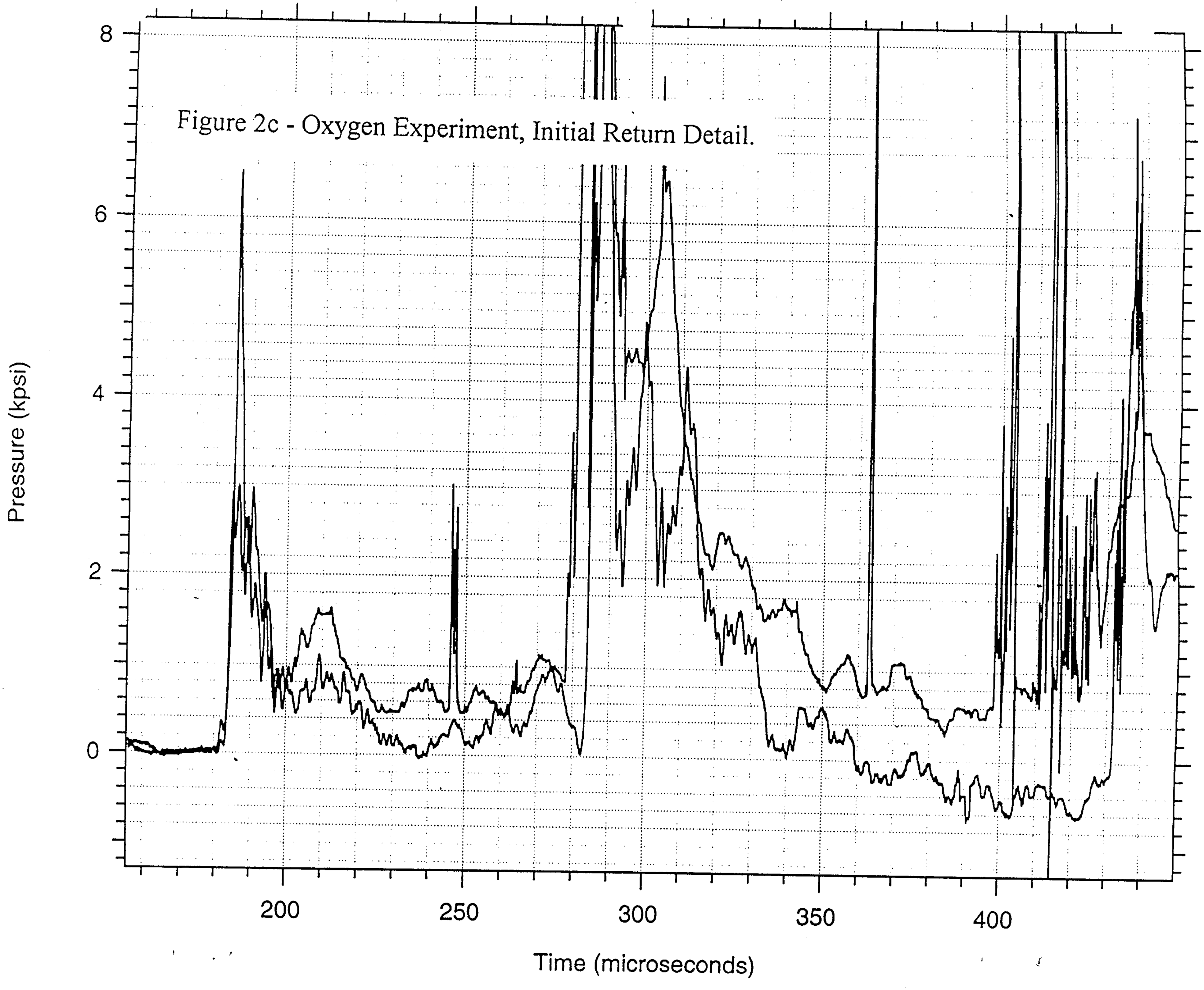

Figure 2c - Oxygen Experiment, Initial Return Detail.

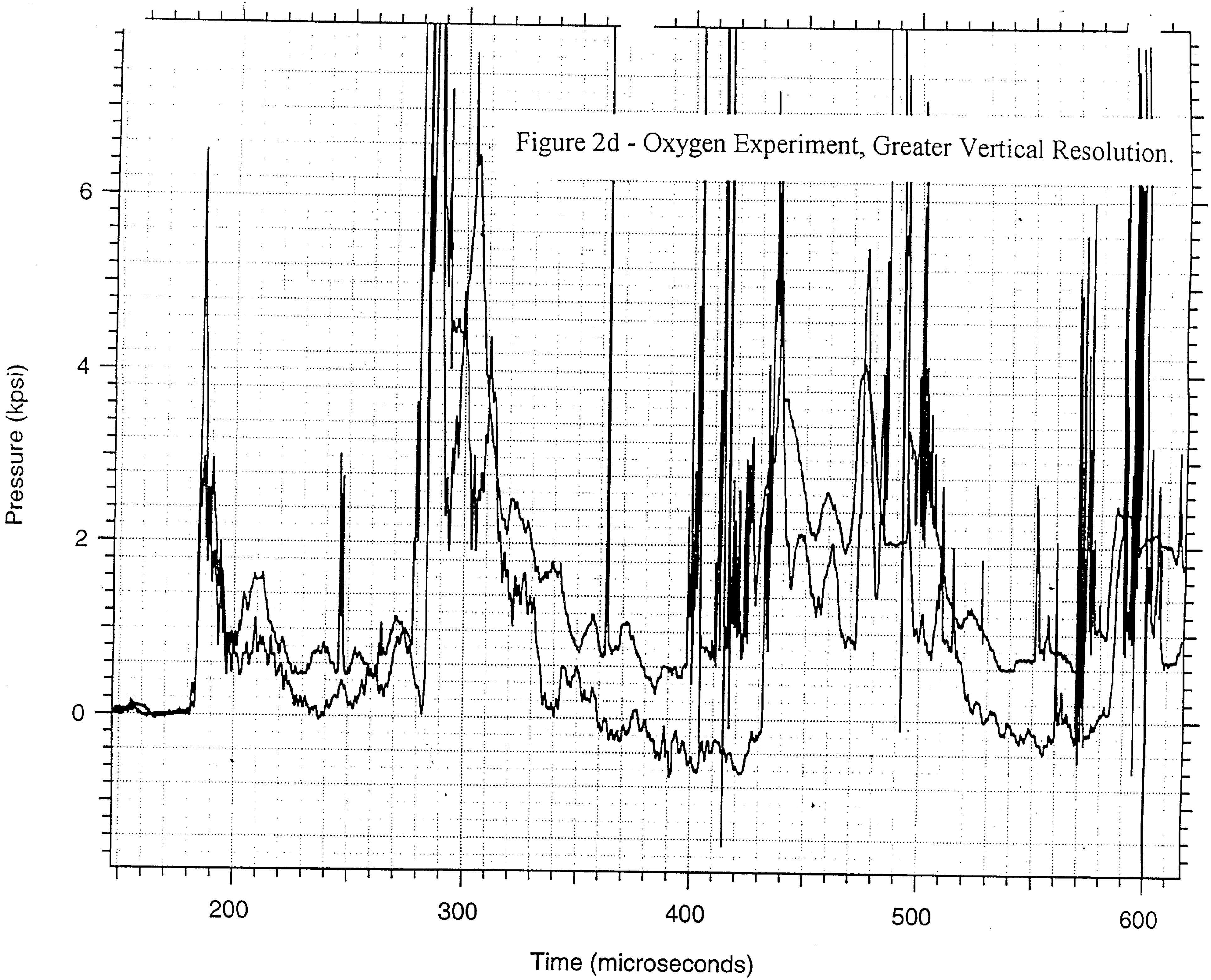
Figure 2d - Oxygen Experiment, Greater Vertical Resolution.
Pressure (kpsi)
6
4
2
0
200
300
400
500
600
Time (microseconds)

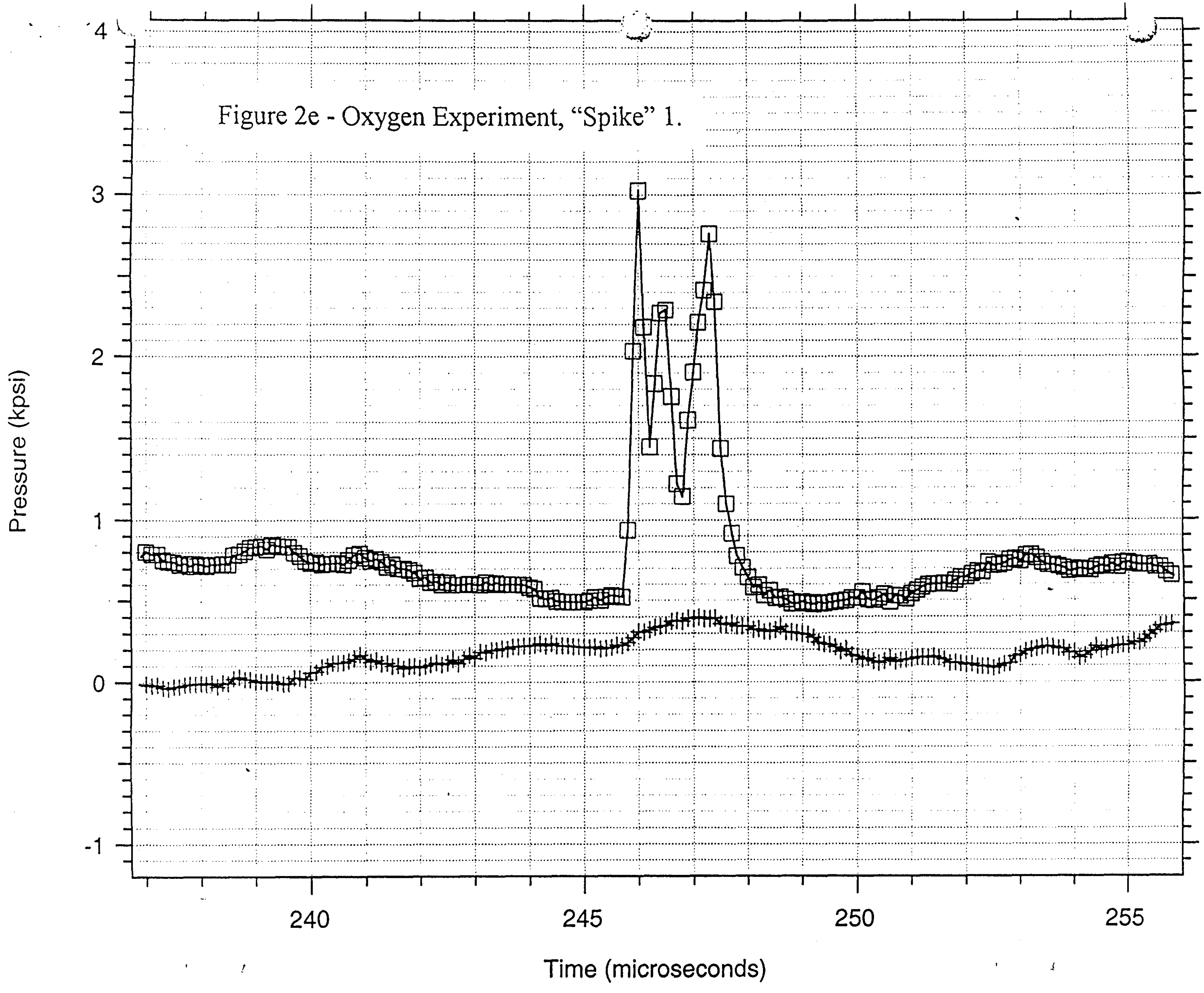
Figure 2e - Oxygen Experiment, "Spike" 1.
Pressure (kpsi)
4
3
2
1
0
-1
240
245
250
255
Time (microseconds)

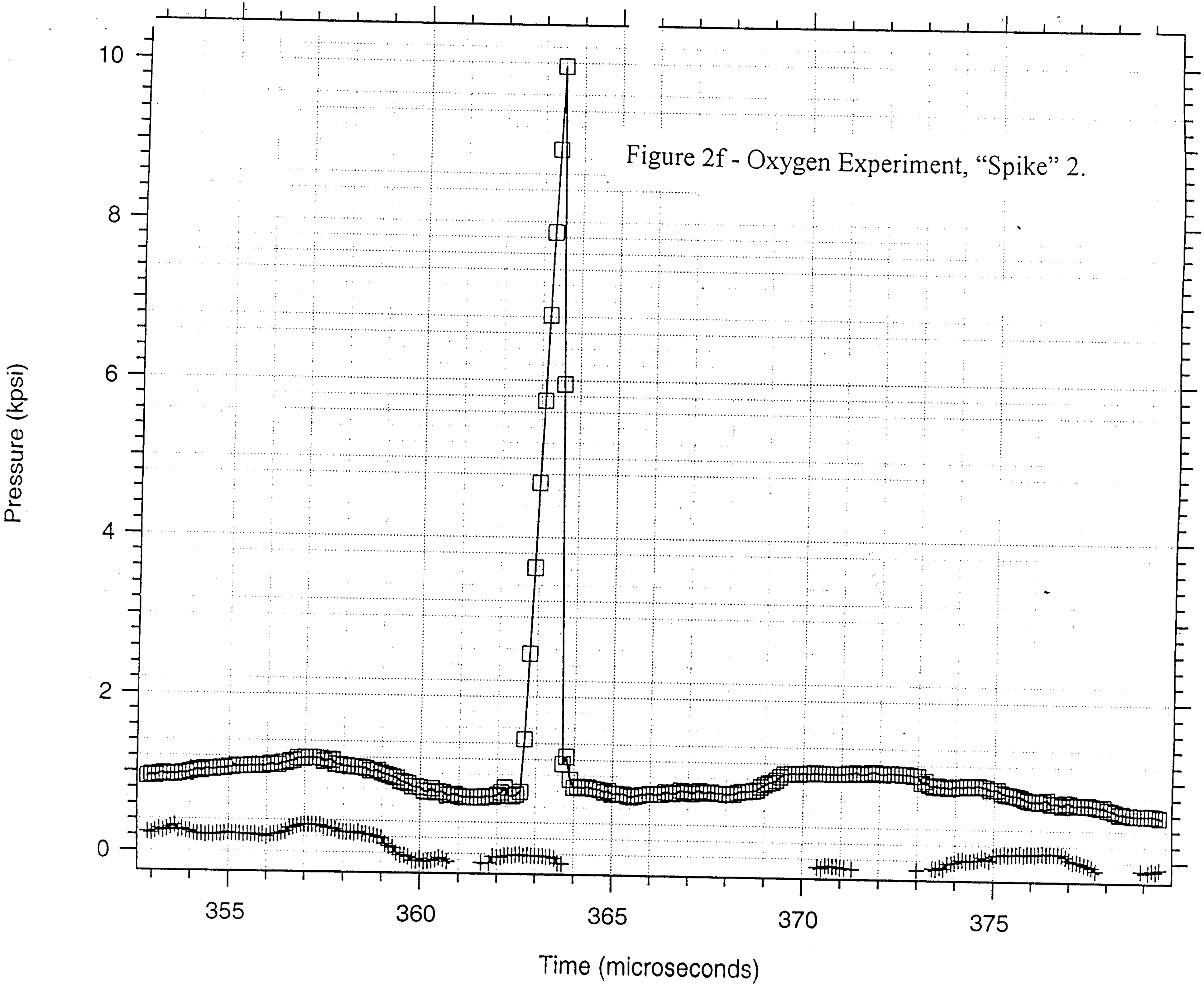

Figure 2f - Oxygen Experiment, "Spike" 2.
Pressure (kpsi)
10
8
6
4
2
0
355
360
365
370
375
Time (microseconds)

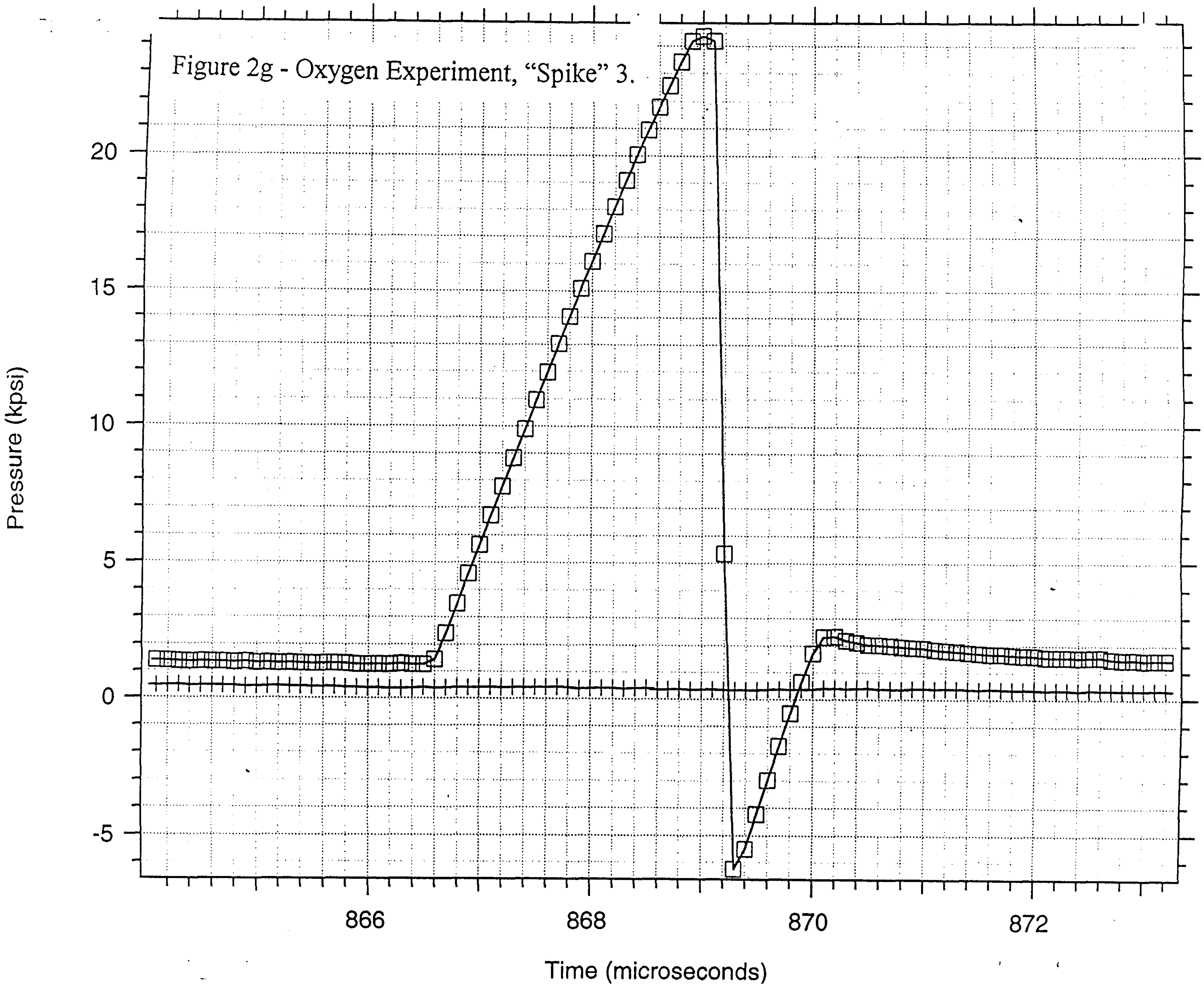
Figure 2g - Oxygen Experiment, "Spike" 3.
Pressure (kpsi)
20
15
10
5
0
-5
866
868
870
872
Time (microseconds)

Appendix 2

LAWRENCE LIVERMORE NATIONAL LABORATORY
CHEMISTRY AND MATERIALS SCIENCE DEPARTMENT
Analytical Sciences Division
Organic Analysis Section

ANALYTICAL GAS MASS SPECTROMETRY SAMPLE ANALYSIS REPORT

REQUESTOR: Bruce Cunningham
ACCT. NO.: 6717-09

REPORT DATE: 8/6/98
ANALYSIS DATE: 8/3/98

SAMPLE: DSWA 1
RUN NO.: 17409

RESULTS: All results are expressed in mole (volume) percent unless otherwise specified.

Component		Concentration	Std. Dev. (%)
Nitrogen	N_2	50.150	1.25
Oxygen	O_2	< 0.01	
Argon	Ar	< 0.01	
Carbon Dioxide	CO_2	3.421	0.08
Carbon Monoxide	CO	28.833	1.46
Hydrogen	H_2	15.944	0.37
Ammonia	NH_3	< 1.0*	
Hydrogen Cyanide	HCN	< 1.0*	
Nitric Oxide	NO	< 0.5*	
Methane	CH_4	1.652	0.04
Hydrocarbons greater than Methane	C_nH_{2n+2}	< 0.1	

* Analyte is not typically measured at sub % levels on this instrumentation.
Report limits are reported as an **estimated** sensitivity level for these "active" compounds.

If you have any questions, feel free to call me at extension 2-7774.

Chris Harvey
Chemist

LAWRENCE LIVERMORE NATIONAL LABORATORY
CHEMISTRY AND MATERIALS SCIENCE DEPARTMENT
Analytical Sciences Division
Organic Analysis Section

ANALYTICAL GAS MASS SPECTROMETRY SAMPLE ANALYSIS REPORT

REQUESTOR: Bruce Cunningham
ACCT. NO.: 6717-09

REPORT DATE: 8/6/98
ANALYSIS DATE: 8/3/98

SAMPLE: DSWA 1 Replicate
RUN NO.: 17420

RESULTS: All results are expressed in mole (volume) percent unless otherwise specified.

Component		Concentration	Std. Dev. (%)
Nitrogen	N_2	49.931	1.28
Oxygen	O_2	< 0.01	
Argon	Ar	< 0.01	
Carbon Dioxide	CO_2	3.435	0.08
Carbon Monoxide	CO	28.972	1.51
Hydrogen	H_2	16.008	0.38
Ammonia	NH_3	< 1.0*	
Hydrogen Cyanide	HCN	< 1.0*	
Nitric Oxide	NO	< 0.5*	
Methane	CH_4	1.654	0.04
Hydrocarbons greater than Methane	C_nH_{2n+2}	< 0.1	

* Analyte is not typically measured at sub % levels on this instrumentation.
Report limits are reported as an estimated sensitivity level for these "active" compounds.

If you have any questions, feel free to call me at extension 2-7774.

Chris Harvey
Chemist

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CHEMISTRY AND MATERIALS SCIENCE DEPARTMENT
Analytical Sciences Division
Organic Analysis Section

ANALYTICAL GAS MASS SPECTROMETRY SAMPLE ANALYSIS REPORT

REQUESTOR: Bruce Cunningham
ACCT. NO.: 6717-09

REPORT DATE: 8/6/98
ANALYSIS DATE: 8/3/98

SAMPLE: DSWA 2
RUN NO.: 17410

RESULTS: All results are expressed in mole (volume) percent unless otherwise specified.

Component		Concentration	Std. Dev. (%)
Nitrogen	N_2	17.015	0.62
Oxygen	O_2	< 0.01	
Argon	Ar	0.110	0.02
Carbon Dioxide	CO_2	58.301	0.52
Carbon Monoxide	CO	19.709	0.85
Hydrogen	H_2	4.865	0.07
Ammonia	NH_3	< 1.0*	
Hydrogen Cyanide	HCN	< 1.0*	
Nitric Oxide	NO	< 0.5*	
Methane	CH_4	< 0.01	
Hydrocarbons greater than Methane	C_nH_{2n+2}	< 0.1	

* Analyte is not typically measured at sub % levels on this instrumentation.
Report limits are reported as an **estimated** sensitivity level for these "active" compounds.

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Chris Harvey
Chemist

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ANALYTICAL GAS MASS SPECTROMETRY SAMPLE ANALYSIS REPORT

REQUESTOR: Bruce Cunningham
ACCT. NO.: 6717-09

REPORT DATE: 8/6/98
ANALYSIS DATE: 8/3/98

SAMPLE: DSWA 2 Replicate
RUN NO.: 17421

RESULTS: All results are expressed in mole (volume) percent unless otherwise specified.

Component		Concentration	Std. Dev. (%)
Nitrogen	N_2	16.793	0.62
Oxygen	O_2	< 0.01	
Argon	Ar	0.115	0.02
Carbon Dioxide	CO_2	58.366	0.52
Carbon Monoxide	CO	19.834	0.85
Hydrogen	H_2	4.892	0.07
Ammonia	NH_3	< 1.0*	
Hydrogen Cyanide	HCN	< 1.0*	
Nitric Oxide	NO	< 0.5*	
Methane	CH_4	< 0.01	
Hydrocarbons greater than Methane	C_nH_{2n+2}	< 0.1	

* Analyte is not typically measured at sub % levels on this instrumentation.
Report limits are reported as an **estimated** sensitivity level for these "active" compounds.

If you have any questions, feel free to call me at extension 2-7774.

Chris Harvey
Chemist

Appendix 3

PEER REVIEW FOR EXPLOSIVES
HEAF or S-300 OPERATIONS
(Valid for 180 days after authorization)
Reference: B191 FSP, Section 5.1.2.12.1; B827 Complex FSP, Appendix D.1

Section I.

Title: Blast Measurements - TNT & Tritonal Peer Review No. 1181

Requester: B. Cunningham Account Number: 6717-09 Date: 6/8/98

Lab/Facility (Room No.): 1K North Explosive Weight: 27 grams (TNT equiv.)

Material Safety Data: Explosive: TNT, Tritonol

Composition TNT (2-Methyl-1,3,5-trinitrobenzene), tritonal (80% TNT, 20% aluminum)

UNO Class/Div/SC Group: 1.1D

Handling Review Date:

Stability Review Date (if applicable):

DH(50): 80cm/106cm DSC Exo: 250°/252°C CRT: .012/.075 cc Spark: no

Friction: Compatibility:[1] no known issues

Any Toxicity: no known issues

Other: Wear latex gloves when handling, do not breathe dust

Disposal Method:

Previous Related Documents:[2]

Job Description: See Attached

Section II.
Approval by PR Committee

Group: I G L Moeriche 6/17/98 Group IV[4]

Group II[5] J W Fork 6/18/98 Group V[6]

Group III L.D. Green 6/19/98 Large Charge Review

Section III.
Approval for HEAF Work

Operator Review[7]

Facility Management[8]

Section IV.
Approval for S-300 Work

Livermore C&MS Representative ______________________________

Concurrence

S-300 Manager ______________________________

Add the following signatures as appropriate:

B827 Complex Facility Manager[9] ______________________________

ES&H Explosives Safety ______________________________

ES&H Team 1 Leader ______________________________

Firing Area Representative ______________________________

Process Area Representative ______________________________

Systems Test Representative ______________________________

Facility Management[8] ______________________________

NOTES:

1. Include names and acceptability's of adhesives planned for use.
2. For work at the B827 Complex, include the number and date of the Peer Review previously reviewed formally by the ES&H Team 1, if this Peer Review will not be submitted to Team 1 for formal review.
3. Include a hazards analysis of intermediaries, unless they are less hazardous than the product.
4. Synthesis operations only.
5. Group II required to verify firing load limit calculations for HEAF only.
6. Directed Energy Experiments only.
7. As required for firing operations by the B191 FSP, Section 5.1.2.12.1.
8. As required by the B191 FSP, Section 5.1.2.12.1. The EMS Leader or Operations Supervisor are alternates to B191 Facility Manager.
9. The B827 Complex Facility Manager delegates signature authority to the B827 Complex Supervisor.

Blast Experiments with TNT and Tritonal

Purpose of the Peer Review

This is a review of blast experiments to be performed in the 1 kilogram north tank, building 191, HEAF. In each experiment approximately 27 grams or less (TNT equivalence) of HE will be detonated, including booster and detonator. The purpose of the experiments will be to monitor blast pressure waves at the wall of a closed pressure vessel. Following the test, the resulting product gasses will be sampled.

Experiment

The experiments will consist of between two and six individual shots. Each shot will involve the detonation of either 25 grams of TNT, or of the energy equivalent mass of Tritonal. The shots will be initiated using a RP2 detonator and a 1.6 gram LX10 booster. The explosive assemblies will be situated inside a closed calorimeter bomb charged with gas, either 1 atmosphere nitrogen or 3 atmospheres oxygen, absolute. A water bath will be used to speed up the post-shot cooling process. Before the 1-K tank is entered and sampling of the gas takes place, the bomb will be cooled so that pressure inside it is sufficiently low to allow manned contact. Attachment A Includes CHEETAH runs to estimate final pressures once the calorimeter has cooled to room temperature. The highest estimated final pressure is for TNT in 3 atmospheres of oxygen yielding a final pressure of 4.1 atmospheres absolute at 293 degrees K.

Shot Assembly

Figure 1 illustrates the calorimeter bomb assembly. The explosive train consists of a pressed 3/4" diameter TNT or Tritonal charge with LX10 wafer booster and 1/4 gram exploding bridgewire detonator (see Figure 2 & 3). The train is suspended within a closed stainless steel calorimeter bomb having an 8.5" I.D. and 11 O.D. " . The bomb used will be one whose useful life has been exceeded (its diameter is too great to allow it to fit within the standard HEAF calorimeter apparatus). The bomb is sealed with 12 grade-8 steel bolts and an O-ring, and has a secondary 1/2" thick steel plate placed on top of the calorimeter lid to reinforce it. The lid has been modified (see Figure 4) to accept two PCB High Frequency Pressure Transducers (#102A03 - See Figure 5). A high pressure tube is connected to the fitting with an autoclave high pressure valve connected to the the end to allow the bomb to be charged with either nitrogen or oxygen prior to the test. This same valve will be used for post test gas sampling and final venting prior to disassembly. A high voltage terminal extends through the lid affording initiation of the explosive train. The bomb itself serves as ground.

Once assembled, the bomb is suspended by cable (see Figure 6) inside a 55 gallon drum, partially filled with water. A plate across the drum provides support. Cables are routed to the high voltage terminal and to the two PCB gages. A thermocouple immersed in the water in the drum is used to determine when the water temperature has reached equilibrium indicating the bomb has cooled and it is appropriate to enter the tank. Upon entry, gas sampling may be performed.

Shots Defined

TNT in oxygen (3 atm absolute)
Tritonal in oxygen (3 atm)
TNT in nitrogen (1 atm)
Tritonal in nitrogen (1 atm)
repeat any of above

Gas Filling the Calorimeter

To gas fill the calorimeter, evacuate the closed bomb and fill to 1 atmosphere with the appropriate gas. Repeat twice more, filling to the required pressure on the third iteration.

Post Shot Gas Sampling

Following the shot, the calorimeter must be allowed to cool in order that the bomb pressure be reduced to a level sufficient to allow entry into the 1 K tank. To insure this, the temperature of the water in the tank must be allowed to come to equilibrium. Upon entry, an evacuated gas sampling vessel will be attached to the outlet side of the autoclave valve. Provision will be made to allow evaluation of the connective link between the autoclave valve and the sampling bottle, prior to sampling. In addition, a pressure gage will be inserted in the link to allow monitoring of the fill pressure. The valve will be opened and the gas sample taken. Thereafter, the remaining gas shall be allowed to vent into the tank exhaust port (with blower turned on) so that the bomb may be dismantled and cleaned. Final purging may be accomplished by removing the high voltage terminal and purging the bomb. During this ventilation process, care must be taken that the operator does not inhale contents of the bomb.

In Case of a Misfire

In the event of a misfire, the operator shall adhere to the procedure described on Attachment B. This is derived from page 3 of section C.2.4 of the HEAF FSP, with the following modification: if disassembly is necessary then prior to disassembling the calorimeter, the operator shall open the pressure valve to vent the calorimeter bomb. If any smoke is observed leaving the vent tube he shall exit the tank and not reinitiate disassembly until the following day.

Figure 1

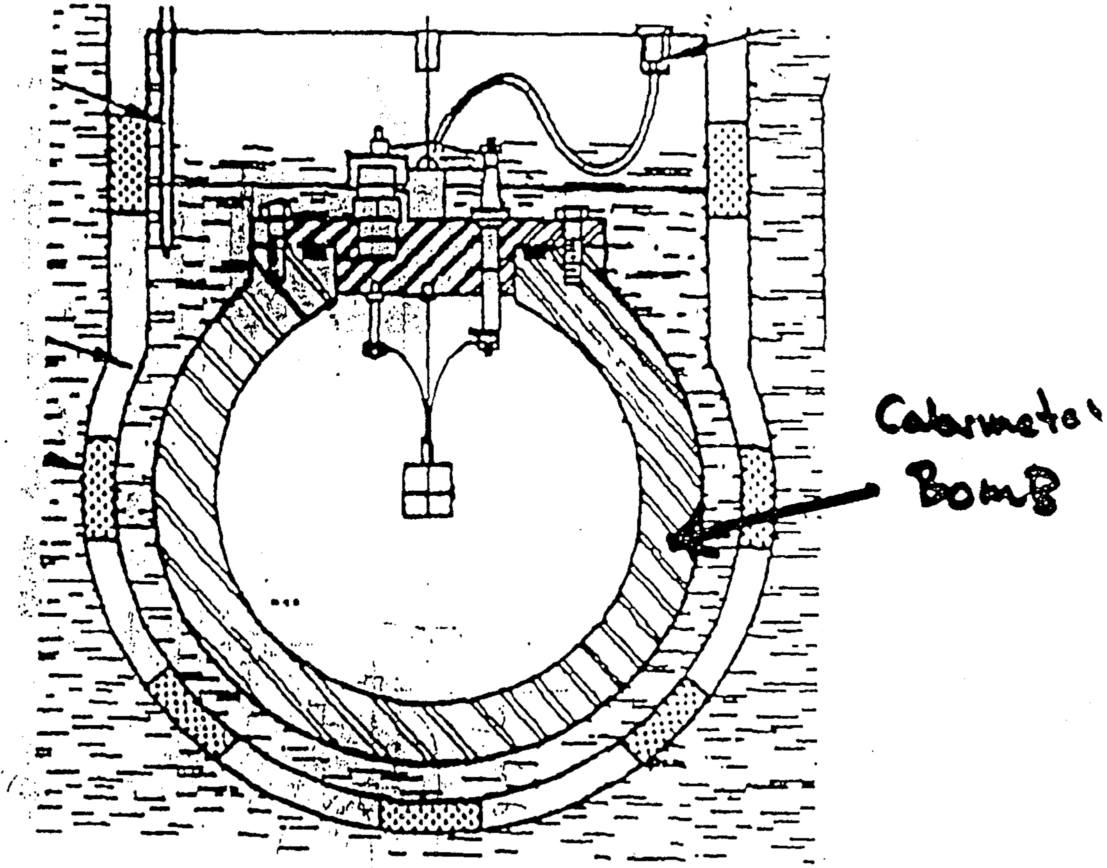
The vessel we will be using is an "expended" calorimeter bomb.

This is an essentially Spherical vessel made from 3.2 cm thick stainless steel.

It has an I.D. of 21.6 cm and an enclosed volume 5.28 litres.

The lid is sealed with an O ring and held in place with 12 1-cm diam. bolts.

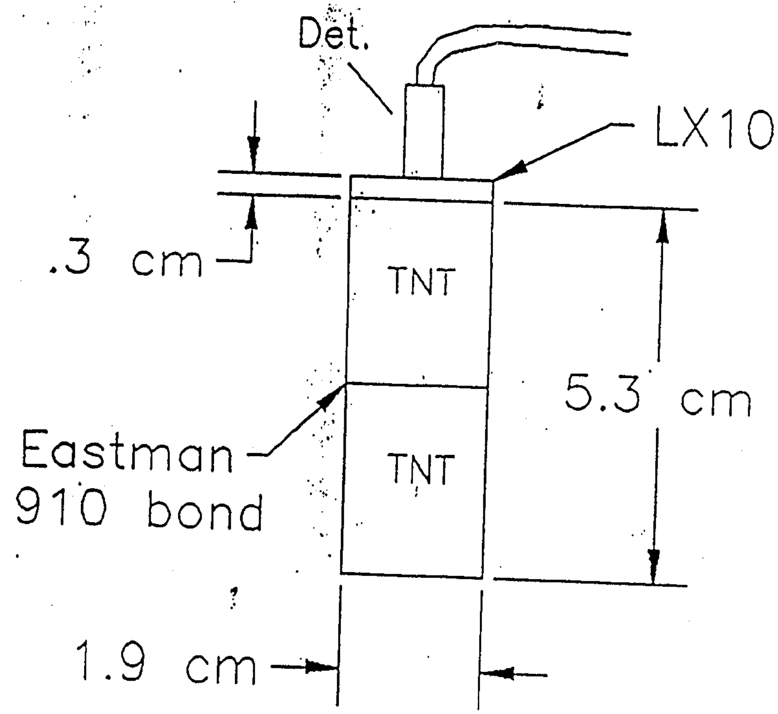
The lid is fitted with a high-voltage terminal, ground screw, and pressure port.



ENERGETIC MATERIALS CENTER

Figure 2

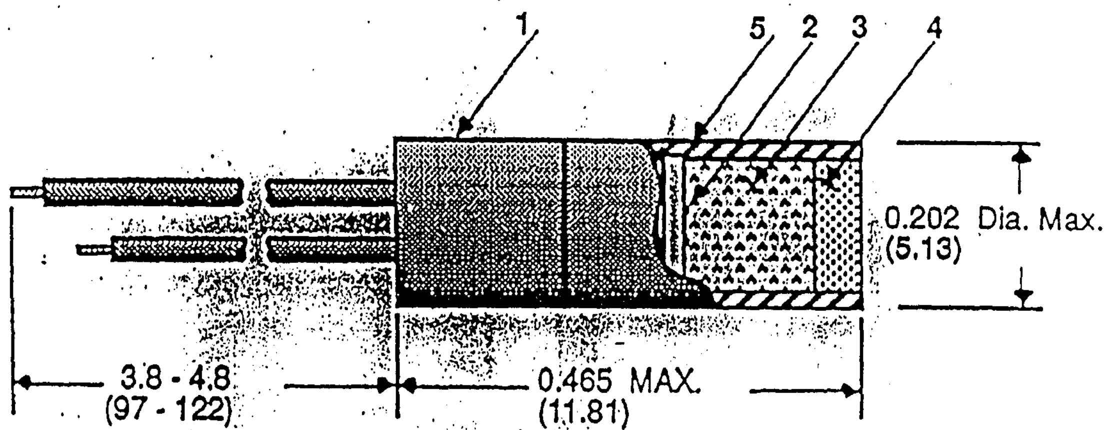
The charge train will be consist of a detonator, LX10 booster, and 1.9 cm diameter pressed parts.



ENERGETIC MATERIALS CENTER

Figure 3

The detonator used will be an RP2 (or LLNL equivalent).



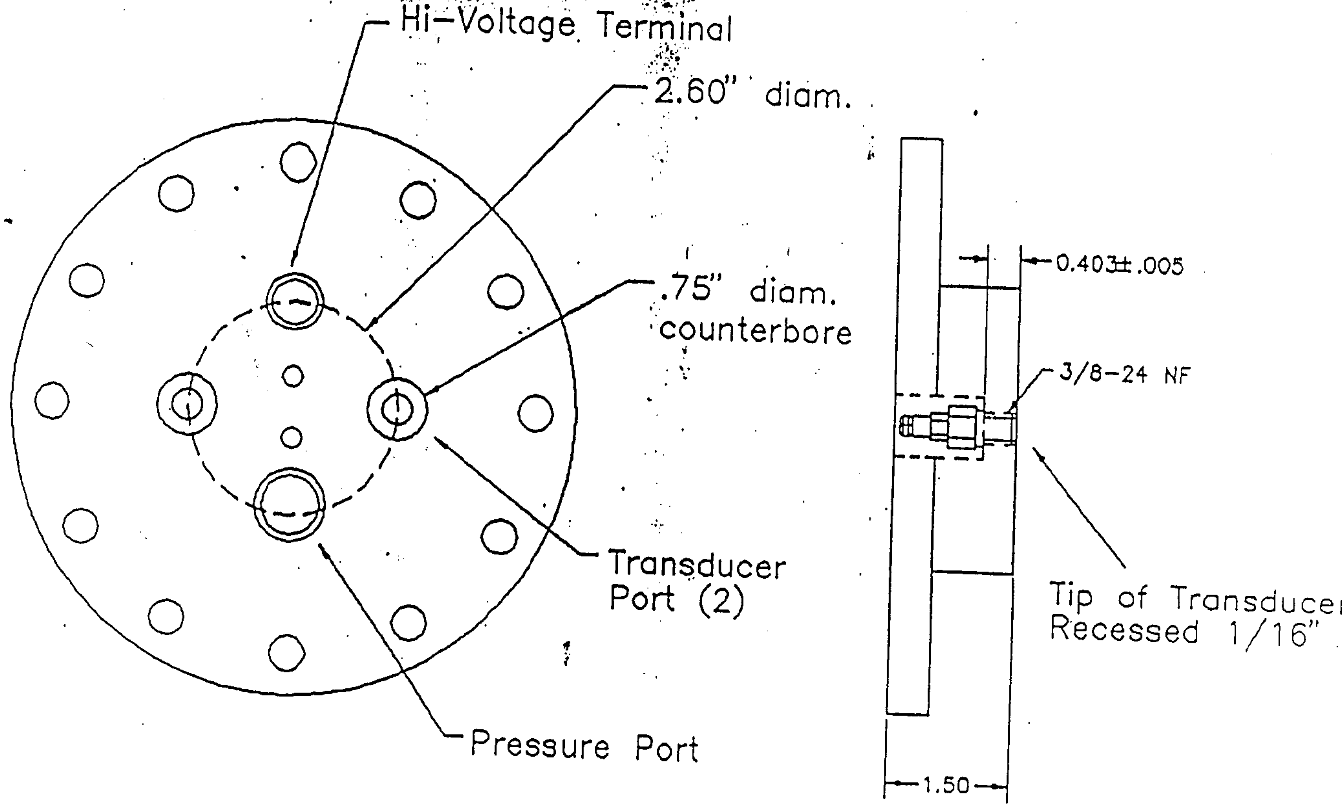
PARTS DESCRIPTION

1. MOLDED HEAD: Diallylphthalate per MIL-M-14 type SDG
2. BRIDGEWIRE: Gold 0.0015 inches in diameter, 0.030 inches long
3. INITIATING EXPLOSIVE: 32 mg of PETN
4. HIGH DENSITY EXPLOSIVE: 18 mg of RDX with binder
5. SLEEVE: Brass, 0.032 thick

EMC ENERGETIC MATERIALS CENTER

Figure 4

We will be modifying the calorimeter lid to accept the pressure transducers



EMC ENERGETIC MATERIALS CENTER

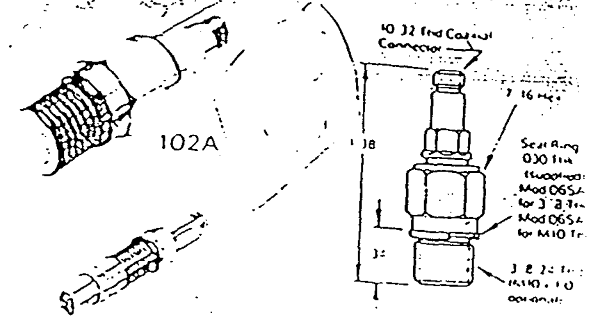
Fig 5

HI-FREQUENCY PRESSURE TRANSDUCER

PCB PRESSURE
PIEZOTRONICS

Series 102A

with built-in amplifier



Alternate Probe version - Series 113A20 (see summary sheet)

See other ranges below specifications

- acceleration-compensated ultra-rigid quartz element
- frequency-tailored non-resonant, one micro-second response
- ground isolation 3/8-24 threaded mount
- high level (5V), low-impedance (100 ohm) analog output
- operation thru ordinary coaxial cable
- flush welded, flat diaphragm

For shock wave, blast, explosion, combustion, compression, actuation, pulsation, cavitation, ultrasonic, aerodynamic, hydraulic, fluidic and other such pressure measurements.

Series 102A transducers consist of seven models. Each model is similar in performance; essentially only the sensitivity, full scale range and discharge time constant are different. Performance features include frequency tailoring, which minimizes resonant frequency amplitude when the transducer is subjected to extremely fast step-pressure inputs. This tailoring results in a clean, accurate, nonresonant output signal. See test result photo lower right. Output is a high voltage signal at low impedance which is capable of driving long ordinary coaxial cable in dirty field, factory or underwater environments.

Shock tube results show these frequency-tailored transducers to be almost completely free of ringing and other internal resonance effects that can distort the signal. The rigid structure of these sophisticated instruments contains a compression mode quartz element with an integral compensating accelerometer to reduce vibration sensitivity and suppress resonance effects. Nearly non-resonant behavior is primarily achieved by meticulously matching the resonant frequency as well as the acceleration sensitivity of the compensating element to that of the pressure sensing element. A minimum number of quartz plates imparts structural integrity.

The 102A Series quartz transducers install in a 3/8-24 threaded hole. Ground isolation is accomplished by insulating the internal sensor element (see Series 113A20) from the outer 3/8-24 threaded housing. Series 113A20 sensor probes are available as separate items.

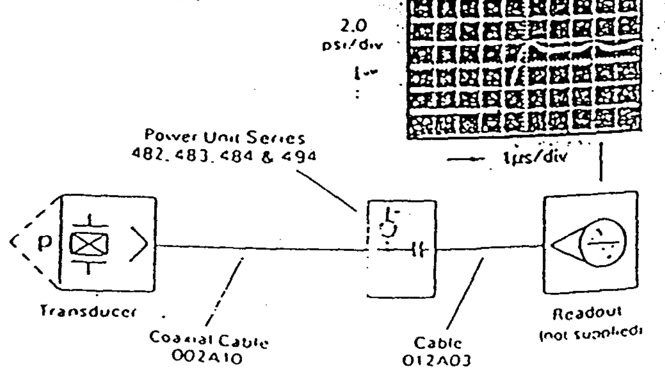
PCB power/signal conditioners provide excitation current to the transducer, remove the output bias voltage and indicate normal or faulty system operation. See information on Series 482, 483, 484 and 494 power units. Higher current to 20 mA is recommended when driving hundreds of feet of cable in field environments.

SPECIFICATIONS: Model No		102A
Range (5V output)	psi	5000
Useful Overrange	psi	10000
Maximum Pressure	psi	15000
Resolution	psi	0.1
Sensitivity	mV/psi	1 ±.05
Frequency (nonresonant)	kHz	500
Rise Time	μs	1.0
Discharge Time Constant	s	500
Low Frequency Response (-5%)	Hz	.001
Linearity (zero based BSL)	%	1.0
Polarity		positive
Output Impedance	ohm	100
Output Bias	V	+9 to 12
Overload Recovery	μs	10
Acceleration Sensitivity	psi/g	.002
Temp Coefficient	%°F	.03
Temperature Range	°F	-100 to +275
Flash Temp (max)	°F	3000
Vibration/Shock	g peak	2000/20000
Sealing (connector)		epoxy
Case/Diaphragm (welded)	mat'l	17-4/invar
Weight	gm	11
Connector (microdot)	coaxial	10-32
Excitation (constant current)	mA	2 to 20
Voltage to Current Regulator	VDC	+18 to 28
Optional 5V Ranges:		
500 psi, 50 second DTC	10 mV/psi	102A06
1000 psi, 100 second DTC	5 mV/psi	102A04
10000 psi, 1000 second DTC	0.5 mV/psi	102A03

Two NBS traceable calibration certificates are furnished with each transducer with data taken at 5 points 0 to full scale and 0 to 10% of full scale.

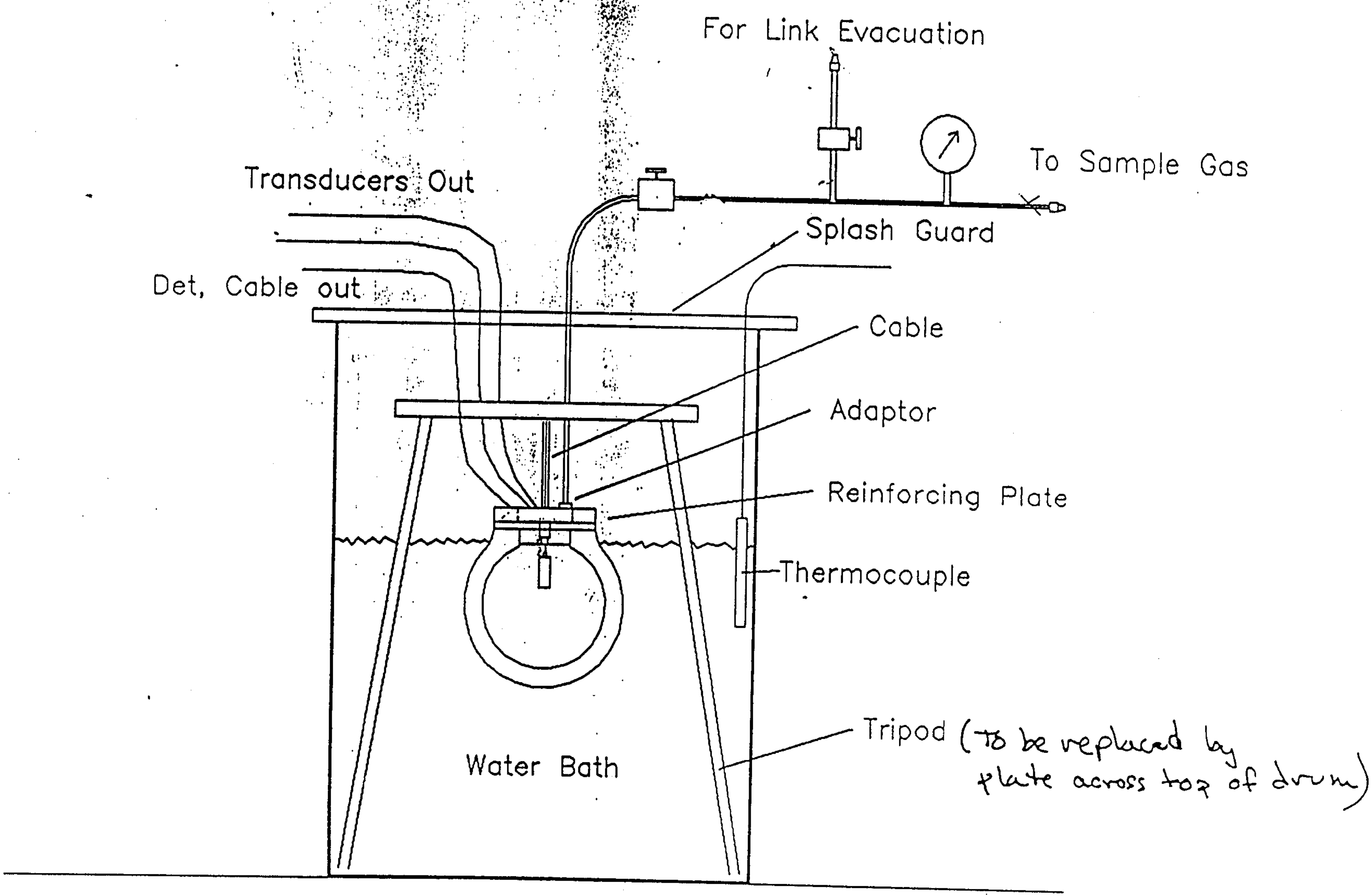
To specify options, add prefix before Model number:
Hermetic sealing prefix "H", e.g. H102A
Metric (M10x1 mtg thd) prefix "M", e.g. M102A
Hermetic & Metric prefix "HM", e.g. HM102A

TYPICAL SYSTEM



102784

Fig 6


For Link Evacuation
To Sample Gas
Transducers Out
Splash Guard
Det, Cable out
Cable
Adaptor
Reinforcing Plate
Thermocouple
Tripod (to be replaced by plate across top of drum)
Water Bath

composition, tnt, 25, hmx, 1.51, viton, 0.09, oxygen, 7.57, weight
point, p, 100000.000000, t, 3000.000000
explosion, rho, 0.006471
point, V, 154.520000, T, 293.000000

First Run – TNT

CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH

CHEETAH version 1.40
Energetic Materials Center
Lawrence Livermore National Laboratory
Technical contact: Dr. Laurence E. Fried

The time is Mon Jun 15 12:24:11 1998

Product library title: cheetah bkw
Executing library command: solver, max newton iterations, 25
Executing library command: solver, max newton retries, 5
Executing library command: solver, min condensed concentration, -1.5125
Executing library command: solver, gas penalty, 0.0
Executing library command: solver, badness limit, 180.0
Executing library command: gas eos, bkw
Executing library command: set, bkw, alpha, 0.499123809964
Executing library command: set, bkw, beta, 0.402655787895
Executing library command: set, bkw, theta, 5441.84607543
Executing library command: set, bkw, kappa, 10.8636743138
Product library title: cheetah bkw
Executing library command: solver, max newton iterations, 25
Executing library command: solver, max newton retries, 5
Executing library command: solver, min condensed concentration, -1.5125
Executing library command: solver, gas penalty, 0.0
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Executing library command: gas eos, bkw
Executing library command: set, bkw, alpha, 0.499123809964
Executing library command: set, bkw, beta, 0.402655787895
Executing library command: set, bkw, theta, 5441.84607543
Executing library command: set, bkw, kappa, 10.8636743138
Input>composition, tnt, 25, hmx, 1.51, viton, 0.09, oxygen, 7.57, weight
Reactant library title:## LLNL CHEETAH 1.0 reactant library

The Composition

Name	% wt.	% mol	Heat of formation (cal/mol)	Standard volume (cc/mol)	Standard entropy (cal/K/mol)	Mol. wt.	Formula
tnt	73.16	31.25	-17810	137.30	0.000	227.13	c7h5n3o6
hmx	4.42	1.45	17930	155.46	0.000	296.17	c4h8n8o8
viton	0.26	0.14	-332700	102.50	0.000	187.08	c5h4f7
oxygen	22.15	67.17	0	22315.20	0.000	32.00	o2

Heat of formation = -59.37774 cal/gm
Standard volume = 154.95739 cc/gm
Standard entropy = 0.00000 cal/k/gm
Standard energy = -63.13051 cal/gm

```
The elements and percent by mole
     c             27.032
     h             20.201
     n             12.642
     o             40.017
     f              0.107
The average mol. wt. =  97.016 g/mol
Input>point, p, 100000.000000, t, 3000.000000


                    Reference state = reactants
          H(R) = H--59.38, E(R) = E--63.13, S(R) = S- 0.00


        P            V          T        H(R)       E(R)       S(R)       VGS
      (ATM)       (CC/GM)      (K)    (CAL/GM)   (CAL/GM) (CAL/K/GM)  (CC/GM)
 1.)  100000.0     0.5715    3000.0    862.04    -518.37     1.549     0.5410

Product concentrations
        Name    (mol/kg) (mol gas/mol explosive)
    co2  Gas   9.946e+000  9.649e-001
    h2o  Gas   8.592e+000  8.336e-001
     co  Gas   5.789e+000  5.616e-001
     n2  Gas   5.428e+000  5.266e-001
   cf2o  Gas   4.506e-002  4.372e-003
  ch2o2  Gas   2.308e-002  2.239e-003
    ch4  Gas   1.702e-002  1.652e-003
     h2  Gas   1.462e-002  1.419e-003
   c2h4  Gas   2.578e-003  2.501e-004
    h3n  Gas   1.636e-003  1.587e-004
   chfo  Gas   1.344e-003  1.304e-004
  ch3oh  Gas   8.279e-004  8.032e-005
     no  Gas   3.049e-004  2.958e-005
   ch2o  Gas   2.887e-004  2.801e-005
   chf3  Gas   1.398e-005  1.357e-006
     o2  Gas   7.476e-006  7.253e-007
  ch2f2  Gas   2.422e-006  2.350e-007
    ch3  Gas   1.311e-006  1.272e-007
   c2h6  Gas   2.535e-007  2.460e-008
    no2  Gas   3.647e-012  3.538e-013
     hf  Gas   4.220e-019  4.094e-020
     *c Solid  7.388e+000  7.168e-001
  Total Gas    2.986e+001  2.897e+000
Input>explosion, rho, 0.006471


The Constant Volume Explosion State:

                    Reference state = reactants
          H(R) = H--59.38, E(R) = E--63.13, S(R) = S- 0.00


        P            V          T        H(R)       E(R)       S(R)       VGS
      (ATM)       (CC/GM)      (K)    (CAL/GM)   (CAL/GM) (CAL/K/GM)  (CC/GM)
 1.)    86.2     154.5356    4185.5    318.72       0.00     2.425   154.5356

Product concentrations
```

	Name	(mol/kg)	(mol gas/mol explosive)
co	Gas	1.955e+001	1.897e+000
h2o	Gas	5.380e+000	5.219e-001
n2	Gas	5.099e+000	4.947e-001
co2	Gas	3.613e+000	3.505e-001
h2	Gas	3.292e+000	3.194e-001
o2	Gas	7.498e-001	7.274e-002
no	Gas	6.583e-001	6.387e-002
cf2o	Gas	4.356e-002	4.226e-003
chfo	Gas	4.343e-003	4.213e-004
no2	Gas	4.920e-004	4.773e-005
h3n	Gas	1.264e-004	1.226e-005
ch2o2	Gas	1.019e-004	9.891e-006
ch2o	Gas	7.938e-005	7.701e-006
chf3	Gas	1.620e-005	1.572e-006
ch2f2	Gas	1.889e-006	1.832e-007
ch3	Gas	4.964e-007	4.816e-008
ch4	Gas	3.207e-008	3.111e-009
hf	Gas	5.540e-009	5.375e-010
ch3oh	Gas	4.566e-009	4.429e-010
c2h4	Gas	1.402e-012	1.360e-013
c2h6	Gas	9.636e-017	9.349e-018
*c	Solid	0.000e+000	0.000e+000
Total	Gas	3.840e+001	3.725e+000

```
Input>point, V, 154.520000, T, 293.000000
Too many iterations in the etanewt solver
The initial damping was too small
Undertaking a gradient line search instead
Too many iterations in the etanewt solver
The initial damping was too small
Undertaking a gradient line search instead
Too many iterations in the etanewt solver
```

Reference state = reactants
H(R) = H--59.38, E(R) = E--63.13, S(R) = S- 0.00

expected final pressure at 293 K

	P (ATM)	V (CC/GM)	T (K)	H(R) (CAL/GM)	E(R) (CAL/GM)	S(R) (CAL/K/GM)	VGS (CC/GM)
1.)	4.2	154.5200	293.0	-1656.02	-1668.13	1.287	154.4723

Product concentrations

	Name	(mol/kg)	(mol gas/mol explosive)	6 moles
co2	Gas	1.288e+001	1.250e+000	6.82
h2o	Gas	8.585e+000	8.329e-001	2.65
n2	Gas	5.429e+000	5.267e-001	.53
ch4	Gas	4.034e-002	3.914e-003	
cf2o	Gas	2.096e-002	2.033e-003	
chf3	Gas	1.653e-002	1.604e-003	
h3n	Gas	1.934e-005	1.876e-006	
h2	Gas	1.377e-005	1.336e-006	.05
ch2f2	Gas	9.850e-009	9.556e-010	
co	Gas	1.482e-010	1.438e-011	.38
c2h6	Gas	6.689e-011	6.490e-012	
chfo	Gas	1.991e-011	1.932e-012	
ch2o2	Gas	6.249e-013	6.063e-014	
ch3oh	Gas	3.538e-017	3.432e-018	

ch2o	Gas	5.559e-021	5.393e-022
c2h4	Gas	2.149e-023	2.085e-024
ch3	Gas	8.674e-035	8.415e-036
o2	Gas	3.720e-043	3.609e-044
no	Gas	3.720e-043	3.609e-044
no2	Gas	3.720e-043	3.609e-044
hf	Gas	3.720e-043	3.609e-044
*c	Solid	1.026e+001	9.951e-001
Total	Gas	2.697e+001	2.617e+000

CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH

CHEETAH version 1.40
Energetic Materials Center
Lawrence Livermore National Laboratory
Technical contact: Dr. Laurence E. Fried

The time is Mon Jun 15 13:38:11 1998

Product library title: cheetah bkw
Executing library command: solver, max newton iterations, 25
Executing library command: solver, max newton retries, 5
Executing library command: solver, min condensed concentration, -1.5125
Executing library command: solver, gas penalty, 0.0
Executing library command: solver, badness limit, 180.0
Executing library command: gas eos, bkw
Executing library command: set, bkw, alpha, 0.499123809964
Executing library command: set, bkw, beta, 0.402655787895
Executing library command: set, bkw, theta, 5441.84607543
Executing library command: set, bkw, kappa, 10.8636743138

reject, *c ← prevents condensation
composition, tnt, 25, hmx, 1.51, viton, 0.09, oxygen, 7.57, weight
point, p, 100000.000000, t, 3000.000000
explosion, rho, 0.006471
point, V, 154.52, T, 293.0

2nd RUN - TNT

CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH

CHEETAH version 1.40
Energetic Materials Center
Lawrence Livermore National Laboratory
Technical contact: Dr. Laurence E. Fried

The time is Mon Jun 15 13:57:46 1998

Product library title: cheetah bkw
Executing library command: solver, max newton iterations, 25
Executing library command: solver, max newton retries, 5
Executing library command: solver, min condensed concentration, -1.5125
Executing library command: solver, gas penalty, 0.0
Executing library command: solver, badness limit, 180.0
Executing library command: gas eos, bkw
Executing library command: set, bkw, alpha, 0.499123809964
Executing library command: set, bkw, beta, 0.402655787895
Executing library command: set, bkw, theta, 5441.84607543
Executing library command: set, bkw, kappa, 10.8636743138
Input>reject, *c
Input>composition, tnt, 25, hmx, 1.51, viton, 0.09, oxygen, 7.57, weight
Reactant library title:## LLNL CHEETAH 1.0 reactant library

The Composition

Name	% wt.	% mol	Heat of formation (cal/mol)	Standard volume (cc/mol)	Standard entropy (cal/K/mol)	Mol. wt.	Formula
tnt	73.16	31.25	-17810	137.30	0.000	227.13	c7h5n3o6
hmx	4.42	1.45	17930	155.46	0.000	296.17	c4h8n8o8
viton	0.26	0.14	-332700	102.50	0.000	187.08	c5h4f7
oxygen	22.15	67.17	0	22315.20	0.000	32.00	o2

Heat of formation = -59.37774 cal/gm
Standard volume = 154.95739 cc/gm
Standard entropy = 0.00000 cal/k/gm
Standard energy = -63.13051 cal/gm

The elements and percent by mole

c	27.032
h	20.201
n	12.642
o	40.017
f	0.107

he average mol. wt. = 97.016 g/mol
Input>point, p, 100000.000000, t, 3000.000000

Reference state = reactants
H(R) = H--59.38, E(R) = E--63.13, S(R) = S- 0.00

	P (ATM)	V (CC/GM)	T (K)	H(R) (CAL/GM)	E(R) (CAL/GM)	S(R) (CAL/K/GM)	VGS (CC/GM)
1.)	100000.0	0.6232	3000.0	1157.97	-347.53	1.629	0.6232

Product concentrations

	Name	(mol/kg)	(mol gas/mol explosive)
co	Gas	1.396e+001	1.355e+000
co2	Gas	7.160e+000	6.947e-001
h2o	Gas	5.953e+000	5.776e-001
n2	Gas	5.426e+000	5.264e-001
c2h4	Gas	6.874e-001	6.669e-002
ch4	Gas	6.229e-001	6.043e-002
cf2o	Gas	4.413e-002	4.282e-003
ch2o2	Gas	3.581e-002	3.474e-003
h2	Gas	3.469e-002	3.366e-003
ch3oh	Gas	9.119e-003	8.847e-004
h3n	Gas	5.430e-003	5.268e-004
chfo	Gas	3.084e-003	2.992e-004
ch2o	Gas	1.520e-003	1.475e-004
c2h6	Gas	1.506e-004	1.461e-005
no	Gas	9.589e-005	9.303e-006
chf3	Gas	4.333e-005	4.204e-006
ch3	Gas	3.408e-005	3.306e-006
ch2f2	Gas	1.745e-005	1.693e-006
o2	Gas	7.318e-007	7.100e-008
no2	Gas	3.641e-013	3.532e-014
hf	Gas	4.508e-019	4.373e-020
Total	Gas	3.395e+001	3.293e+000

Input>explosion, rho, 0.006471

The Constant Volume Explosion State:

Reference state = reactants
H(R) = H--59.38, E(R) = E--63.13, S(R) = S- 0.00

	P (ATM)	V (CC/GM)	T (K)	H(R) (CAL/GM)	E(R) (CAL/GM)	S(R) (CAL/K/GM)	VGS (CC/GM)
1.)	86.2	154.5356	4185.5	318.72	0.00	2.425	154.5356

Product concentrations

	Name	(mol/kg)	(mol gas/mol explosive)
co	Gas	1.955e+001	1.897e+000
h2o	Gas	5.380e+000	5.219e-001
n2	Gas	5.099e+000	4.947e-001
co2	Gas	3.613e+000	3.505e-001
h2	Gas	3.292e+000	3.194e-001
o2	Gas	7.498e-001	7.274e-002
no	Gas	6.583e-001	6.387e-002
cf2o	Gas	4.356e-002	4.226e-003
chfo	Gas	4.343e-003	4.213e-004
no2	Gas	4.920e-004	4.773e-005

h3n	Gas	1.264e-004	1.226e-005
ch2o2	Gas	1.019e-004	9.891e-006
ch2o	Gas	7.938e-005	7.701e-006
chf3	Gas	1.620e-005	1.572e-006
ch2f2	Gas	1.889e-006	1.832e-007
ch3	Gas	4.964e-007	4.816e-008
ch4	Gas	3.207e-008	3.111e-009
hf	Gas	5.540e-009	5.375e-010
ch3oh	Gas	4.566e-009	4.429e-010
c2h4	Gas	1.402e-012	1.360e-013
c2h6	Gas	9.636e-017	9.349e-018
Total	Gas	3.840e+001	3.725e+000

```
Input>point, V, 154.52, T, 293.0
Too many iterations in the etanewt solver
```

Reference state = reactants

H(R) = H--59.38, E(R) = E--63.13, S(R) = S- 0.00

	P (ATM)	V (CC/GM)	T (K)	H(R) (CAL/GM)	E(R) (CAL/GM)	S(R) (CAL/K/GM)	VGS (CC/GM)
1.)	4.1	154.5200	293.0	-1609.86	-1621.38	1.275	154.5200

Product concentrations

	Name	(mol/kg)	(mol gas/mol explosive)
co2	Gas	1.688e+001	1.637e+000
n2	Gas	5.429e+000	5.267e-001
c2h6	Gas	2.749e+000	2.667e-001
co	Gas	5.923e-001	5.746e-002
ch4	Gas	2.083e-001	2.021e-002
cf2o	Gas	1.913e-002	1.856e-003
chf3	Gas	1.775e-002	1.722e-003
c2h4	Gas	1.356e-003	1.316e-004
ch2f2	Gas	1.785e-008	1.732e-009
chfo	Gas	3.069e-011	2.977e-012
h2	Gas	8.935e-015	8.668e-016
h2o	Gas	1.827e-018	1.772e-019
h3n	Gas	3.208e-019	3.112e-020
ch2o	Gas	1.446e-020	1.403e-021
ch2o2	Gas	5.331e-022	5.172e-023
ch3oh	Gas	5.990e-026	5.812e-027
ch3	Gas	1.756e-029	1.703e-030
o2	Gas	3.720e-043	3.609e-044
no	Gas	3.720e-043	3.609e-044
no2	Gas	3.720e-043	3.609e-044
hf	Gas	3.720e-043	3.609e-044
Total	Gas	2.589e+001	2.512e+000

```
title, calo_trit1 first run tritonal
composition, tnt, 18.24, al, 4.56, hmx, 1.51, viton, .09, oxygen, 7.57, weight
point, p, 100000.0, t, 3000.0
explosion, rho, .006054
point, V, 165.15, T, 293.0
```

CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH CHEETAH

CHEETAH version 1.40
Energetic Materials Center
Lawrence Livermore National Laboratory
Technical contact: Dr. Laurence E. Fried

The time is Tue Jun 16 09:30:34 1998

Product library title: cheetah bkw
Executing library command: solver, max newton iterations, 25
Executing library command: solver, max newton retries, 5
Executing library command: solver, min condensed concentration, -1.5125
Executing library command: solver, gas penalty, 0.0
Executing library command: solver, badness limit, 180.0
Executing library command: gas eos, bkw
Executing library command: set, bkw, alpha, 0.499123809964
Executing library command: set, bkw, beta, 0.402655787895
Executing library command: set, bkw, theta, 5441.84607543
Executing library command: set, bkw, kappa, 10.8636743138
Product library title: cheetah bkw
Executing library command: solver, max newton iterations, 25
Executing library command: solver, max newton retries, 5
Executing library command: solver, min condensed concentration, -1.5125
Executing library command: solver, gas penalty, 0.0
Executing library command: solver, badness limit, 180.0
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Executing library command: set, bkw, beta, 0.402655787895
Executing library command: set, bkw, theta, 5441.84607543
Executing library command: set, bkw, kappa, 10.8636743138
Reactant library title:## LLNL CHEETAH 1.0 reactant library

The Composition

Name	% wt.	% mol	Heat of formation (cal/mol)	Standard volume (cc/mol)	Standard entropy (cal/K/mol)	Mol. wt.	Formula
tnt	57.05	16.34	-17810	137.30	0.000	227.13	c7h5n3o6
al	14.26	34.39	100	9.98	0.000	26.98	al1
hmx	4.72	1.04	17930	155.46	0.000	296.17	c4h8n8o8
viton	0.28	0.10	-332700	102.50	0.000	187.08	c5h4f7
oxygen	23.68	48.13	0	22315.20	0.000	32.00	o2

Heat of formation = -46.35508 cal/gm
Standard volume = 165.54568 cc/gm
Standard entropy = 0.00000 cal/k/gm
Standard energy = -50.36427 cal/gm

```
Input>title, calo_trit1 first run tritonal
Input>composition, tnt, 18.24, al, 4.56, hmx, 1.51, viton, .09, oxygen, 7.5
```

The Composition

Name	% wt.	% mol	Heat of formation (cal/mol)	Standard volume (cc/mol)	Standard entropy (cal/K/mol)	Mol. wt.	Formula
tnt	57.05	16.34	-17810	137.30	0.000	227.13	c7h5n3o6
al	14.26	34.39	100	9.98	0.000	26.98	al1
hmx	4.72	1.04	17930	155.46	0.000	296.17	c4h8n8o8
viton	0.28	0.10	-332700	102.50	0.000	187.08	c5h4f7
oxygen	23.68	48.13	0	22315.20	0.000	32.00	o2

```
Heat of formation =  -46.35508 cal/gm
Standard volume   =  165.54568 cc/gm
Standard entropy  =    0.00000 cal/k/gm
Standard energy   =  -50.36427 cal/gm

The elements and percent by mole
     c             23.600
     h             17.914
     n             11.366
     o             40.175
     al             6.819
     f              0.126
The average mol. wt. =  65.051 g/mol
Input>point, p, 100000.0, t, 3000.0
```

Reference state = reactants

H(R) = H--46.36, E(R) = E--50.36, S(R) = S- 0.00

	P (ATM)	V (CC/GM)	T (K)	H(R) (CAL/GM)	E(R) (CAL/GM)	S(R) (CAL/K/GM)	VGS (CC/GM)
1.)	100000.0	0.4834	3000.0	41.83	-1124.78	1.341	0.3807

Product concentrations

Name		(mol/kg)	(mol gas/mol explosive)
h2o	Gas	6.874e+000	4.472e-001
co2	Gas	6.176e+000	4.018e-001
n2	Gas	4.405e+000	2.865e-001
co	Gas	3.906e+000	2.541e-001
cf2o	Gas	4.828e-002	3.141e-003
ch4	Gas	1.608e-002	1.046e-003
ch2o2	Gas	1.593e-002	1.036e-003
h2	Gas	1.228e-002	7.986e-004
c2h4	Gas	2.392e-003	1.556e-004
h3n	Gas	1.500e-003	9.757e-005
chfo	Gas	1.173e-003	7.630e-005
ch3oh	Gas	7.094e-004	4.614e-005
no	Gas	2.181e-004	1.419e-005
ch2o	Gas	2.121e-004	1.380e-005
chf3	Gas	2.131e-005	1.386e-006
o2	Gas	4.795e-006	3.119e-007
ch2f2	Gas	3.044e-006	1.980e-007
ch3	Gas	1.099e-006	7.146e-008
c2h6	Gas	2.479e-007	1.613e-008

```
The elements and percent by mole
     c              23.600
     h              17.914
     n              11.366
     o              40.175
     al              6.819
     f               0.126
The average mol. wt. =  65.051 g/mol
Input>title, calo_trit1 first run tritonal
Input>composition, tnt, 18.24, al, 4.56, hmx, 1.51, viton, .09, oxygen, 7.5
                                   The Composition

Name       % wt.   % mol  Heat of     Standard    Standard     Mol.   Formula
                          formation   volume      entropy      wt.
                          (cal/mol)   (cc/mol)   (cal/K/mol)
tnt        57.05   16.34   -17810     137.30       0.000     227.13  c7h5n3o6
al         14.26   34.39      100       9.98       0.000      26.98  al1
hmx         4.72    1.04    17930     155.46       0.000     296.17  c4h8n8o8
viton       0.28    0.10  -332700     102.50       0.000     187.08  c5h4f7
oxygen     23.68   48.13        0   22315.20       0.000      32.00  o2

Heat of formation =  -46.35508 cal/gm
Standard volume   =  165.54568 cc/gm
Standard entropy  =    0.00000 cal/k/gm
Standard energy   =  -50.36427 cal/gm

The elements and percent by mole
     c              23.600
     h              17.914
     n              11.366
     o              40.175
     al              6.819
     f               0.126
The average mol. wt. =  65.051 g/mol
Input>point, p, 100000.0, t, 3000.0

                    Reference state = reactants
     H(R) = H--46.36, E(R) = E--50.36, S(R) = S- 0.00

        P           V          T        H(R)       E(R)       S(R)       VGS
      (ATM)      (CC/GM)      (K)     (CAL/GM)   (CAL/GM)  (CAL/K/GM)  (CC/GM)
 1.) 100000.0    -0.4834    3000.0     41.83    -1124.78     1.341     0.3807

Product concentrations
          Name    (mol/kg)  (mol gas/mol explosive)
    h2o   Gas   6.874e+000   4.472e-001
    co2   Gas   6.176e+000   4.018e-001
     n2   Gas   4.405e+000   2.865e-001
     co   Gas   3.906e+000   2.541e-001
   cf2o   Gas   4.828e-002   3.141e-003
    ch4   Gas   1.608e-002   1.046e-003
  ch2o2   Gas   1.593e-002   1.036e-003
     h2   Gas   1.228e-002   7.986e-004
   c2h4   Gas   2.392e-003   1.556e-004
    h3n   Gas   1.500e-003   9.757e-005
```

chfo	Gas	1.173e-003	7.630e-005
ch3oh	Gas	7.094e-004	4.614e-005
no	Gas	2.181e-004	1.419e-005
ch2o	Gas	2.121e-004	1.380e-005
chf3	Gas	2.131e-005	1.386e-006
o2	Gas	4.795e-006	3.119e-007
ch2f2	Gas	3.044e-006	1.980e-007
ch3	Gas	1.099e-006	7.146e-008
c2h6	Gas	2.479e-007	1.613e-008
no2	Gas	2.175e-012	1.415e-013
alo	Gas	7.544e-013	4.907e-014
hf	Gas	3.994e-019	2.598e-020
*c	Solid	8.126e+000	5.286e-001
al2o3	Solid	2.643e+000	1.720e-001
*al	Solid	0.000e+000	0.000e+000
Total	Gas	2.146e+001	1.396e+000

Input>explosion, rho, .006054

The Constant Volume Explosion State:

Reference state = reactants

H(R) = H--46.36, E(R) = E--50.36, S(R) = S- 0.00

	P (ATM)	V (CC/GM)	T (K)	H(R) (CAL/GM)	E(R) (CAL/GM)	S(R) (CAL/K/GM)	VGS (CC/GM)
1.)	76.2	165.1800	4724.5	300.89	0.00	2.242	165.0969

Product concentrations

Name		(mol/kg)	(mol gas/mol explosive)
co	Gas	1.705e+001	1.109e+000
h2	Gas	4.239e+000	2.757e-001
n2	Gas	4.061e+000	2.642e-001
h2o	Gas	2.702e+000	1.758e-001
alo	Gas	1.641e+000	1.067e-001
co2	Gas	1.190e+000	7.743e-002
no	Gas	6.889e-001	4.481e-002
o2	Gas	5.790e-001	3.767e-002
cf2o	Gas	4.638e-002	3.017e-003
chfo	Gas	4.897e-003	3.186e-004
no2	Gas	3.859e-004	2.510e-005
h3n	Gas	1.499e-004	9.752e-006
ch2o	Gas	9.470e-005	6.160e-006
ch2o2	Gas	5.067e-005	3.296e-006
chf3	Gas	4.887e-005	3.179e-006
ch2f2	Gas	5.693e-006	3.703e-007
ch3	Gas	1.805e-006	1.174e-007
hf	Gas	1.090e-007	7.091e-009
ch4	Gas	6.695e-008	4.355e-009
ch3oh	Gas	5.992e-009	3.898e-010
c2h4	Gas	7.086e-012	4.609e-013
c2h6	Gas	4.448e-016	2.893e-017
*c	Solid	0.000e+000	0.000e+000
al2o3	Liquid	1.823e+000	1.186e-001
*al	Solid	0.000e+000	0.000e+000
Total	Gas	3.221e+001	2.095e+000

Input>point V, 165.15, T, 293.0

```
   no2  Gas    2.175e-012  1.415e-013
   alo  Gas    7.544e-013  4.907e-014
    hf  Gas    3.994e-019  2.598e-020
    *c Solid   8.126e+000  5.286e-001
 al2o3 Solid   2.643e+000  1.720e-001
   *al Solid   0.000e+000  0.000e+000
  Total Gas    2.146e+001  1.396e+000
Input>explosion, rho, .006054

The Constant Volume Explosion State:

                              Reference state = reactants
                    H(R) = H--46.36, E(R) = E--50.36, S(R) = S- 0.00

          P            V          T        H(R)       E(R)        S(R)       VGS
        (ATM)       (CC/GM)      (K)     (CAL/GM)   (CAL/GM)  (CAL/K/GM)  (CC/GM)
 1.)      76.2      165.1800   4724.5     300.89       0.00       2.242   165.0969

Product concentrations
          Name    (mol/kg) (mol gas/mol explosive)
     co   Gas    1.705e+001  1.109e+000
     h2   Gas    4.239e+000  2.757e-001
     n2   Gas    4.061e+000  2.642e-001
    h2o   Gas    2.702e+000  1.758e-001
    alo   Gas    1.641e+000  1.067e-001
    co2   Gas    1.190e+000  7.743e-002
     no   Gas    6.889e-001  4.481e-002
     o2   Gas    5.790e-001  3.767e-002
   cf2o   Gas    4.638e-002  3.017e-003
   chfo   Gas    4.897e-003  3.186e-004
    no2   Gas    3.859e-004  2.510e-005
    h3n   Gas    1.499e-004  9.752e-006
   ch2o   Gas    9.470e-005  6.160e-006
  ch2o2   Gas    5.067e-005  3.296e-006
   chf3   Gas    4.887e-005  3.179e-006
  ch2f2   Gas    5.693e-006  3.703e-007
    ch3   Gas    1.805e-006  1.174e-007
     hf   Gas    1.090e-007  7.091e-009
    ch4   Gas    6.695e-008  4.355e-009
  ch3oh   Gas    5.992e-009  3.898e-010
   c2h4   Gas    7.086e-012  4.609e-013
   c2h6   Gas    4.448e-016  2.893e-017
     *c Solid    0.000e+000  0.000e+000
  al2o3 Liquid   1.823e+000  1.186e-001
    *al Solid    0.000e+000  0.000e+000
   Total Gas     3.221e+001  2.095e+000
Input>point, V, 165.15, T, 293.0

                              Reference state = reactants
                    H(R) = H--46.36, E(R) = E--50.36, S(R) = S- 0.00

          P            V          T        H(R)       E(R)        S(R)       VGS
        (ATM)       (CC/GM)      (K)     (CAL/GM)   (CAL/GM)  (CAL/K/GM)  (CC/GM)
 1.)       2.9      165.1500    293.0   -2185.03   -2192.46       0.976   165.0354
```

Product concentrations

	Name	(mol/kg)	(mol gas/mol explosive)
co2	Gas	8.172e+000	5.316e-001
h2o	Gas	6.853e+000	4.458e-001
n2	Gas	4.406e+000	2.866e-001
ch4	Gas	4.067e-002	2.646e-003
chf3	Gas	2.000e-002	1.301e-003
cf2o	Gas	1.891e-002	1.230e-003
h3n	Gas	1.724e-005	1.121e-006
h2	Gas	1.432e-005	9.316e-007
ch2f2	Gas	1.123e-008	7.307e-010
co	Gas	1.223e-010	7.959e-012
c2h6	Gas	6.564e-011	4.270e-012
chfo	Gas	1.695e-011	1.102e-012
ch2o2	Gas	3.846e-013	2.502e-014
ch3oh	Gas	2.744e-017	1.785e-018
ch2o	Gas	4.455e-021	2.898e-022
c2h4	Gas	2.168e-023	1.410e-024
ch3	Gas	8.909e-035	5.796e-036
alo	Gas	3.720e-043	2.420e-044
no	Gas	3.720e-043	2.420e-044
o2	Gas	3.720e-043	2.420e-044
no2	Gas	3.720e-043	2.420e-044
hf	Gas	3.720e-043	2.420e-044
*c	Solid	1.004e+001	6.534e-001
al2o3	Solid	2.643e+000	1.720e-001
*al	Solid	0.000e+000	0.000e+000
Total	Gas	1.951e+001	1.269e+000

— Fire the shot after all shot operations and the Area Secure (Run/Safe) system has been completed.

- **Reentry to Firing Tank After Shot is Fired:** The operator shall:

— Purge the firing tank for a minimum of 35 min (full explosives weight shot) before personnel are allowed to enter the tank.

— Remove the system console key from the control panel.

— Visually verify that the CDU or fireset is fully discharged.

— Reinstall the detonator cable onto the grounding (shorting) panel.

- **Misfire Procedure:** The operator shall:

— Turn off the CDU and all test area voltage circuits.

— Visually verify that all meters are reading zero.

— Wait at least 30 min before entering the Tank Room.

— Notify the Firing Operations Supervisor, FM, and HC Explosives Safety Engineer.

— Attach the detonator cable to the shorting panel.

— Retain possession of the system console key and the HE key.

— Determine the disposition of the misfire in conjunction with the HC Explosives Safety Engineer and the Firing Operations Supervisor or representative.

*
— Package and dispose of any shot debris originating from an incomplete explosives detonation in accordance with existing LLNL procedures.

- **Area Secure Procedure for 1-kg Tank Room 1401 — Run/Safe Operation (Tank Firing Mode):** The operator shall:

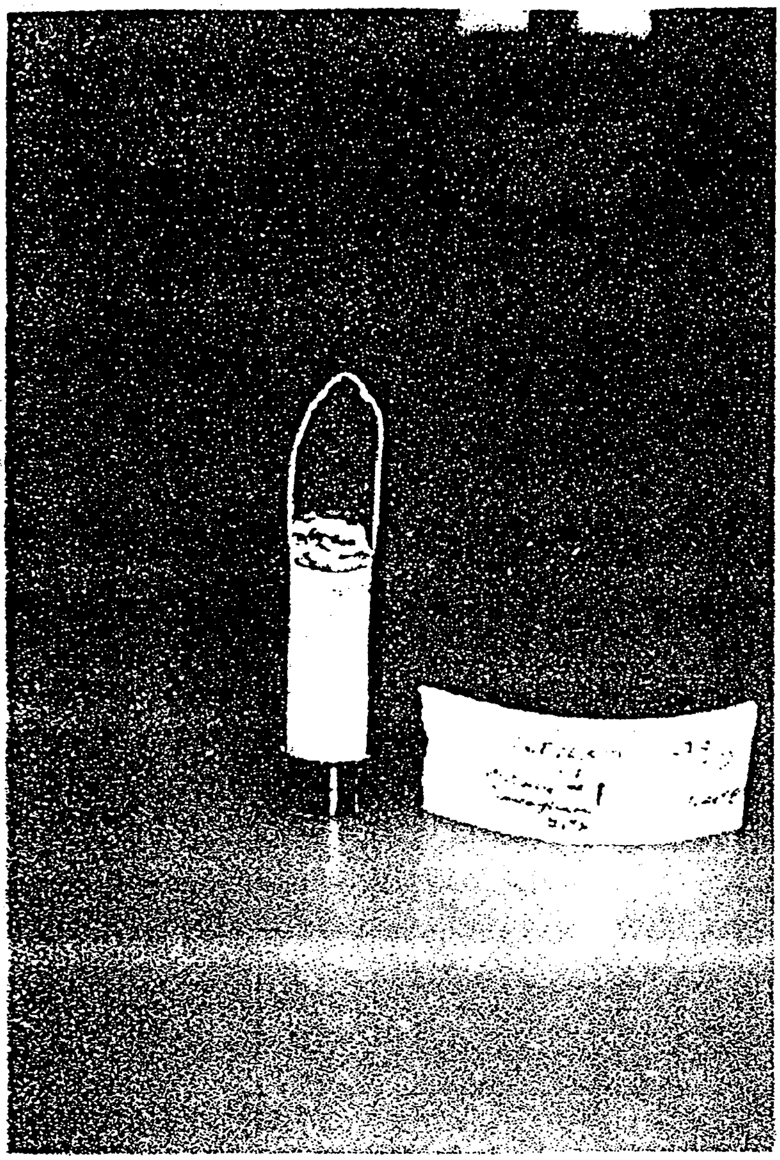
Follow HEAF Procedure 92-014, *Run/Safe Sweep Procedure for 1 kg South Tank System,* to set the sweep for this area.

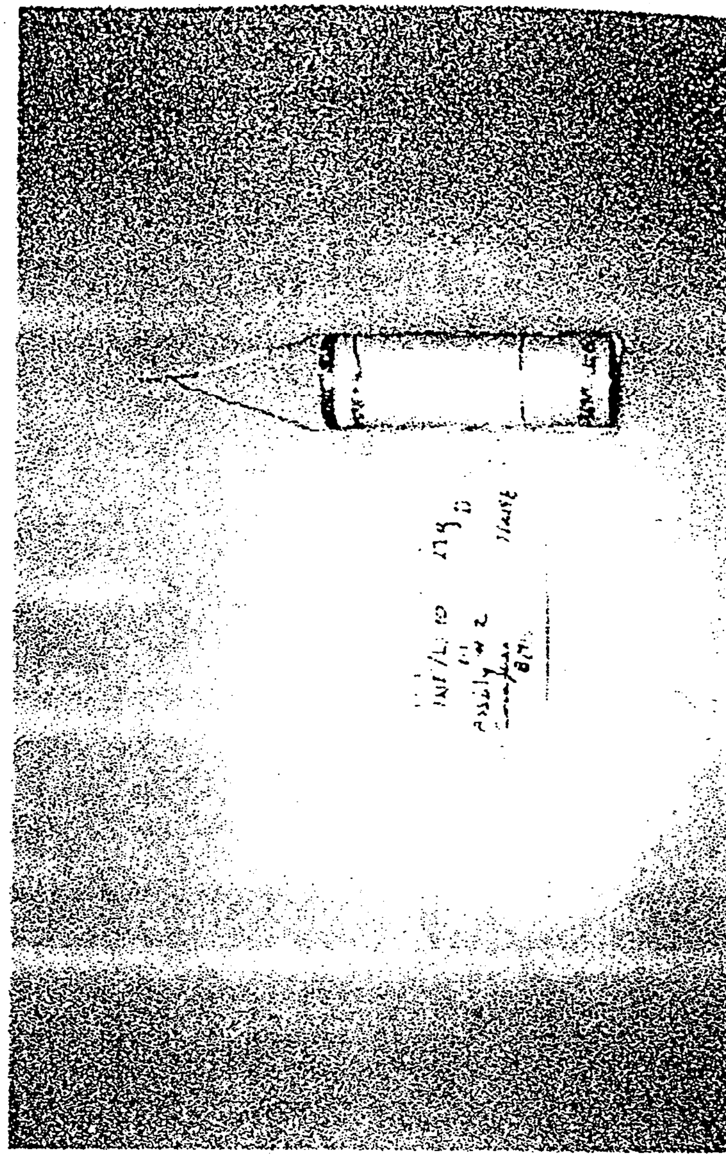
- **Area Secure Procedure for 1-kg Tank Room 1413 — Run/Safe Operation (Tank Firing Mode):** The operator shall:

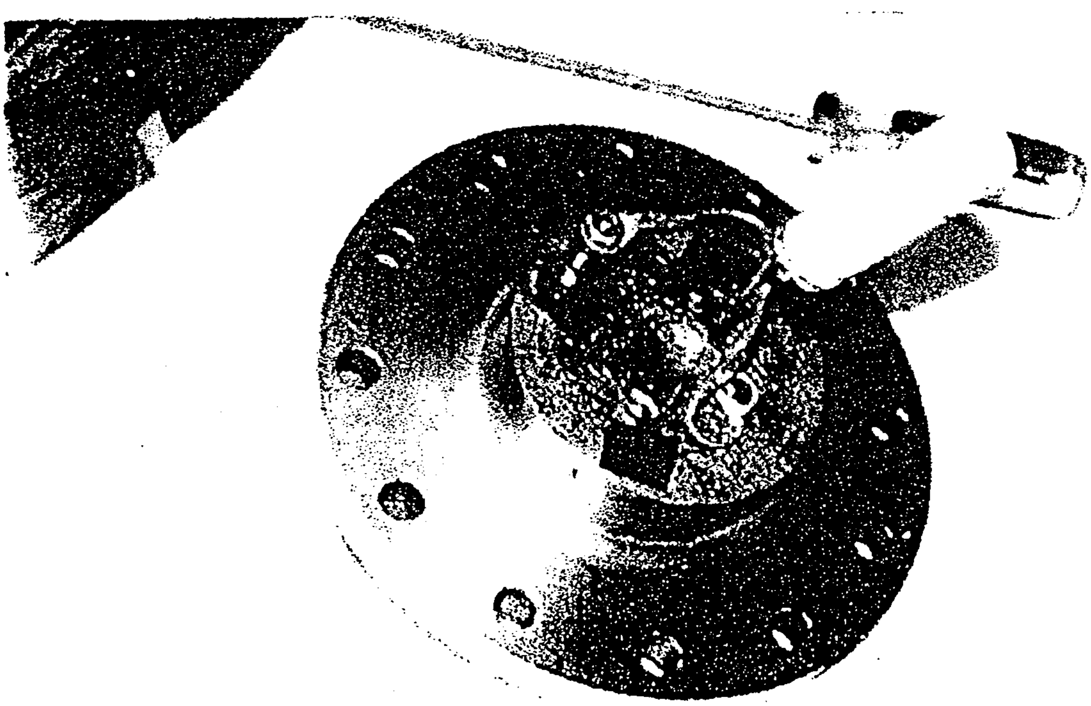
Follow HEAF Procedure 92-015, *Run/Safe Procedure for 1 kg North Tank System,* to set the sweep for this area.

* If calorimeter bomb disassembly is necessary, prior to disassembly the operator shall open the pressure value to vent the bomb. If any smoke is observed leaving the vent tube he shall exit the tank and not reinitiate disassembly until the following day.

Appendix 4





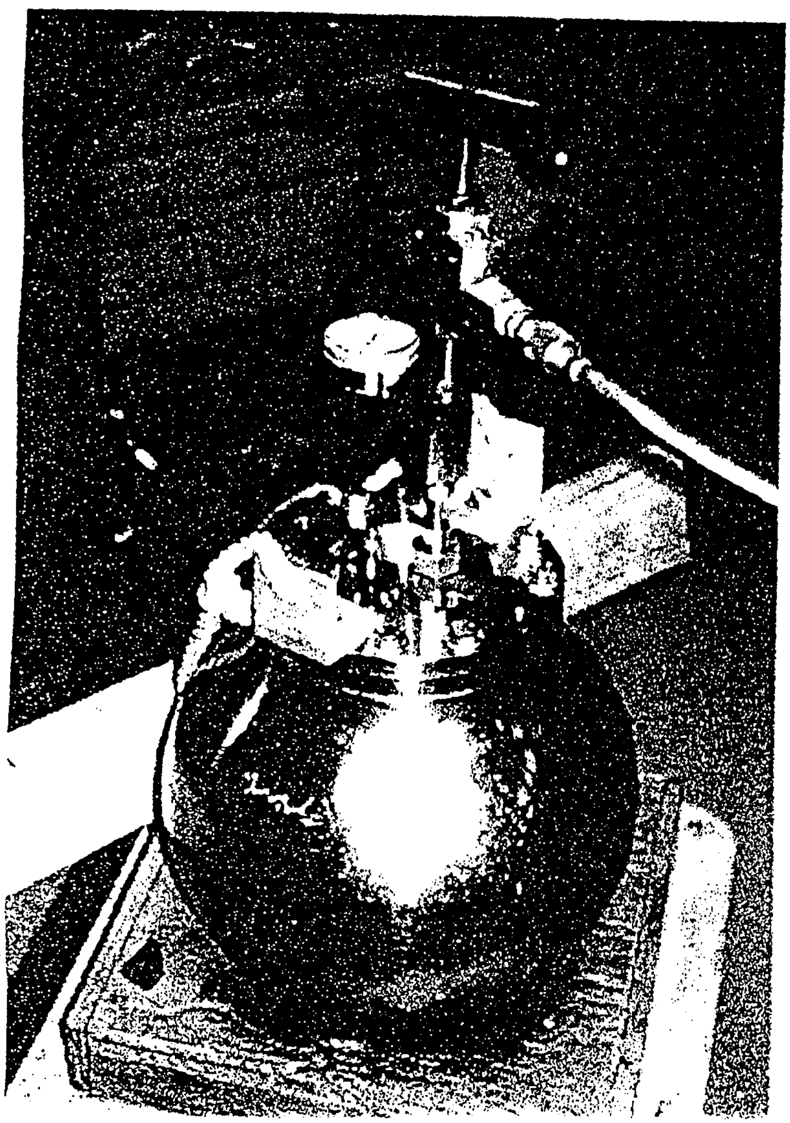


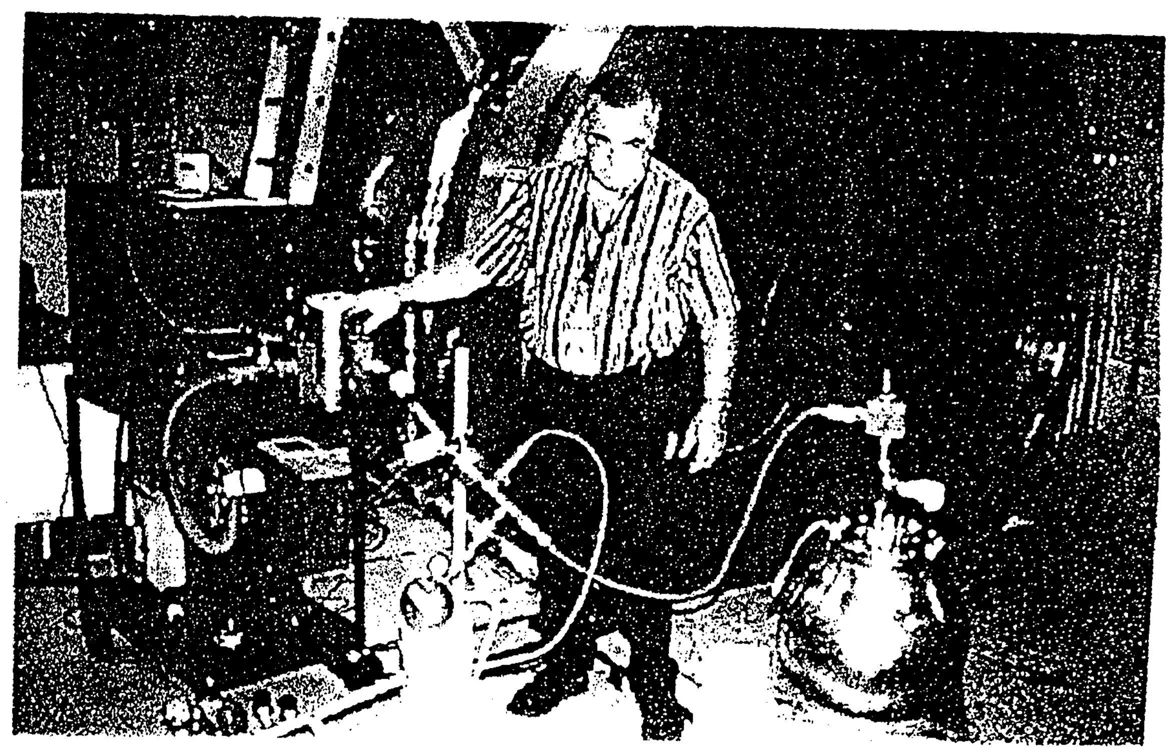
Upper Left - Charge for nitrogen experiment.

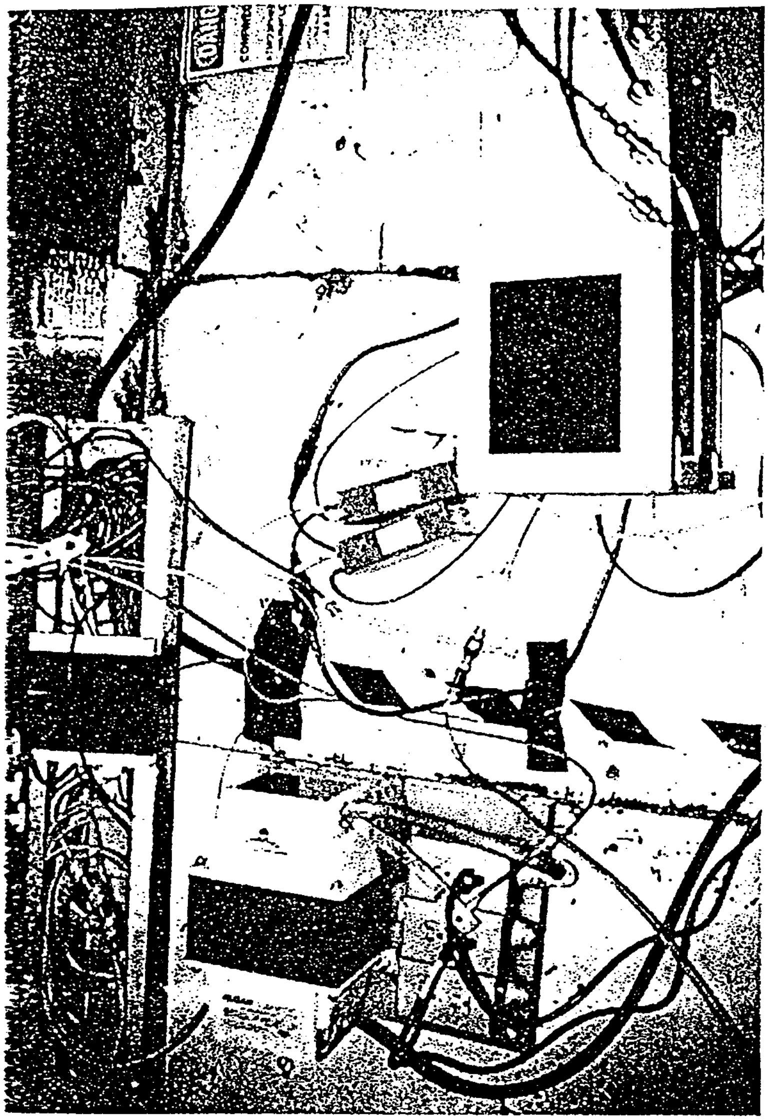
Upper Right - Charge for oxygen experiment.

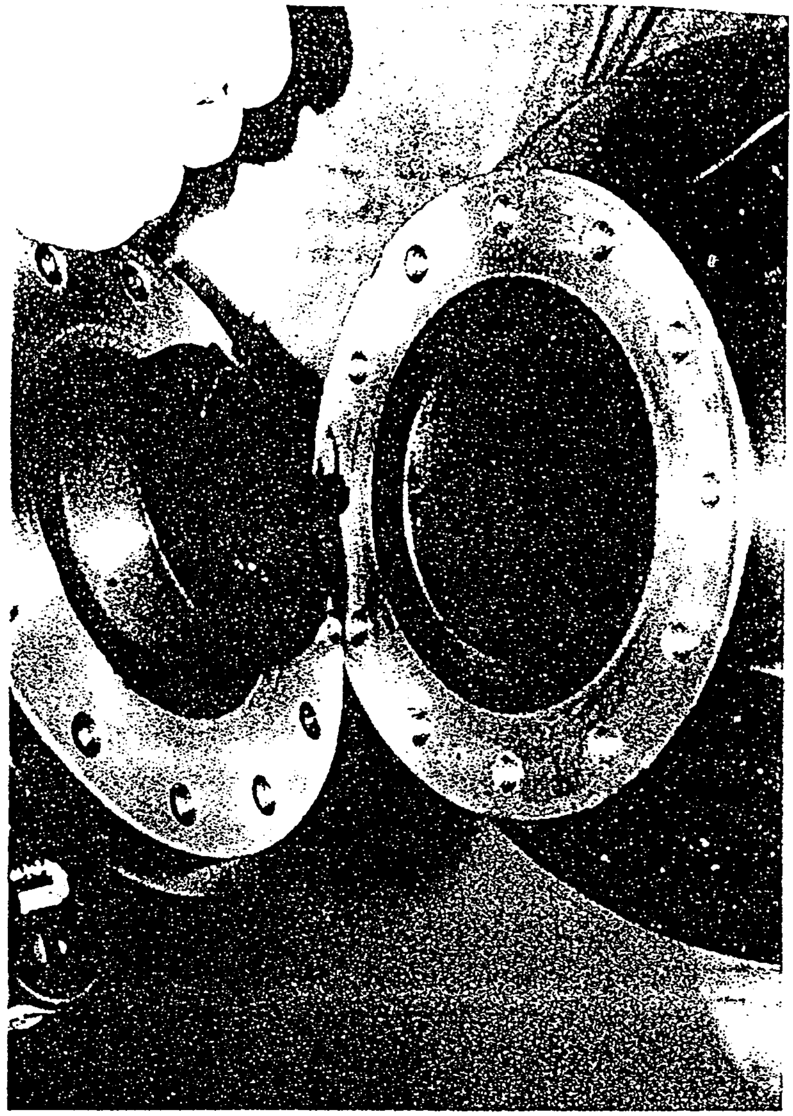
Lower Left - Calorimeter bomb lid with charge attached.

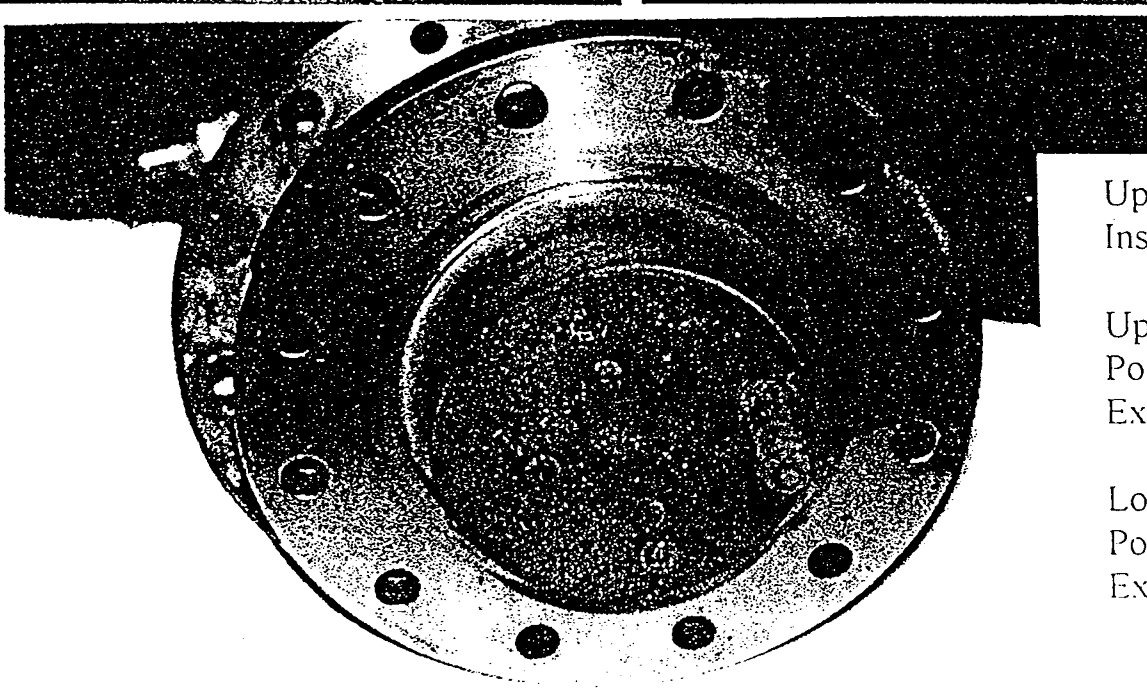
Various views of bomb and gas charging and evacuation system.







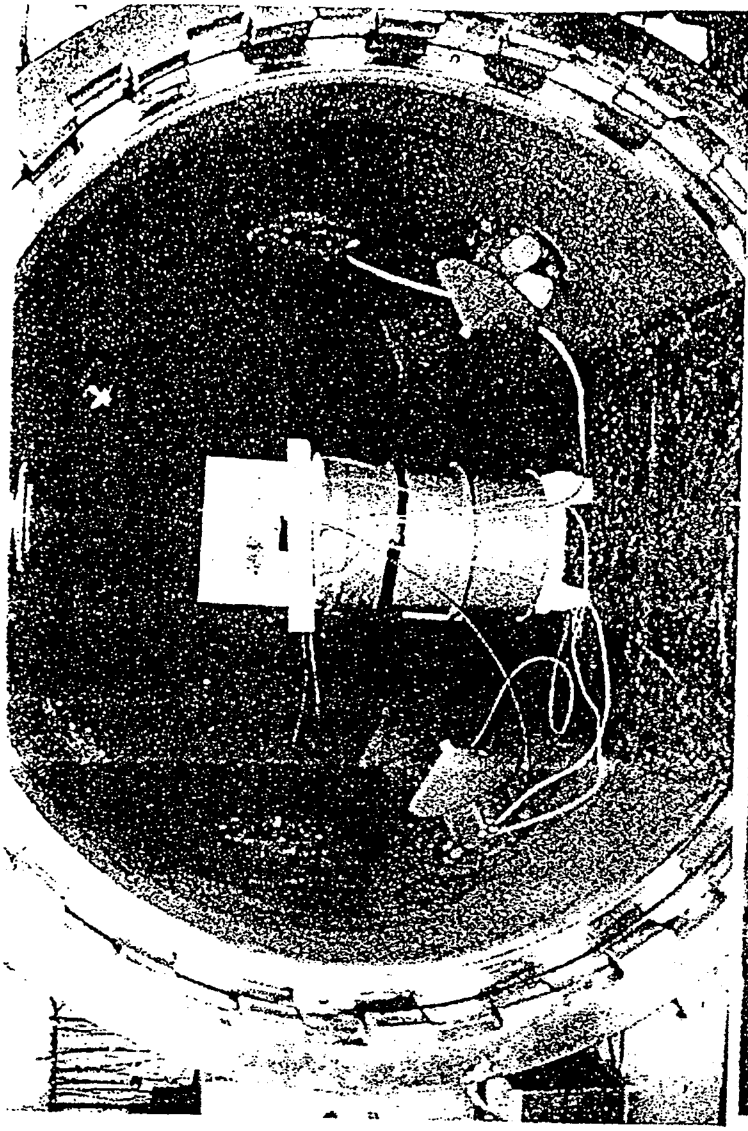


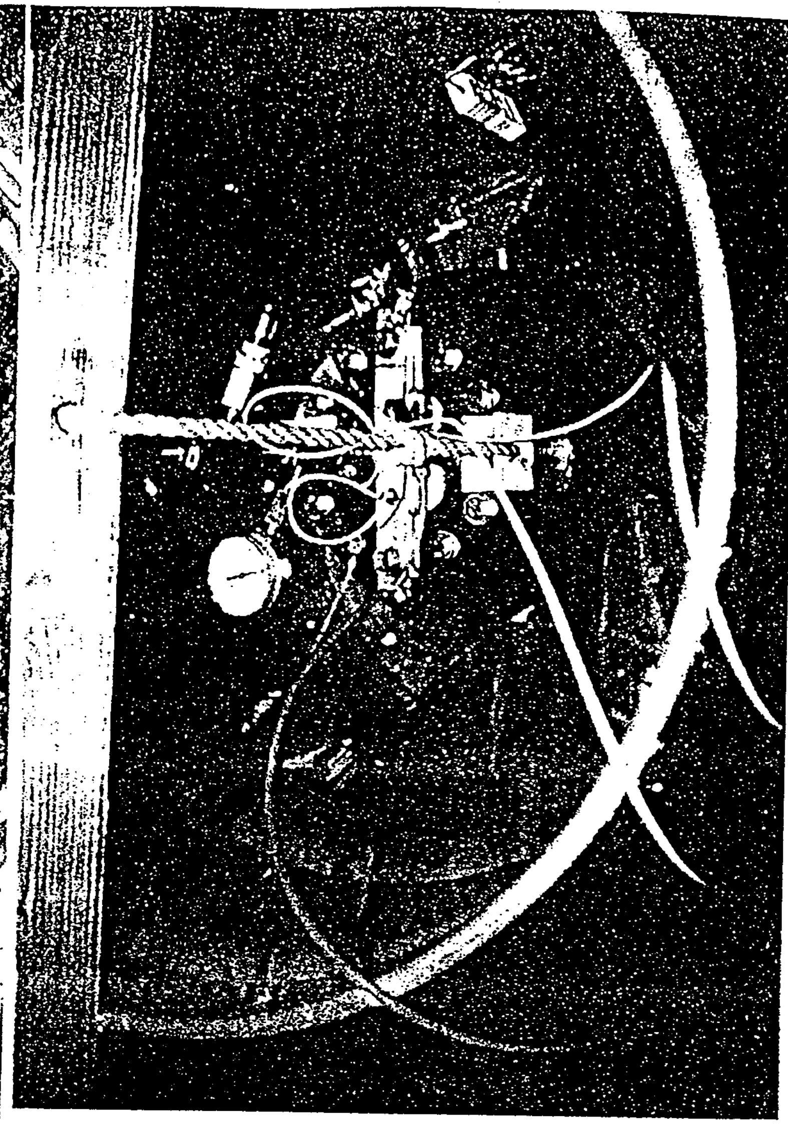


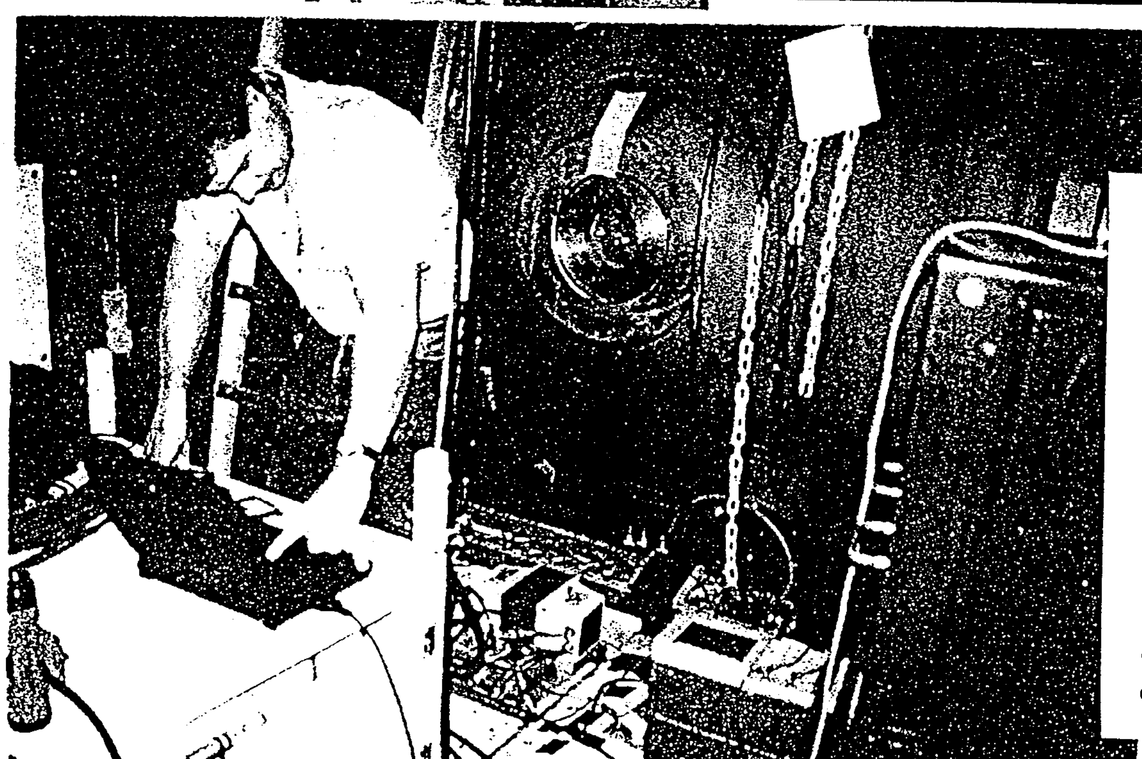
Upper Left -
Instrumentation

Upper Right -
Post Nitrogen
Experiment.

Lower Left -
Post Oxygen
Experiment.



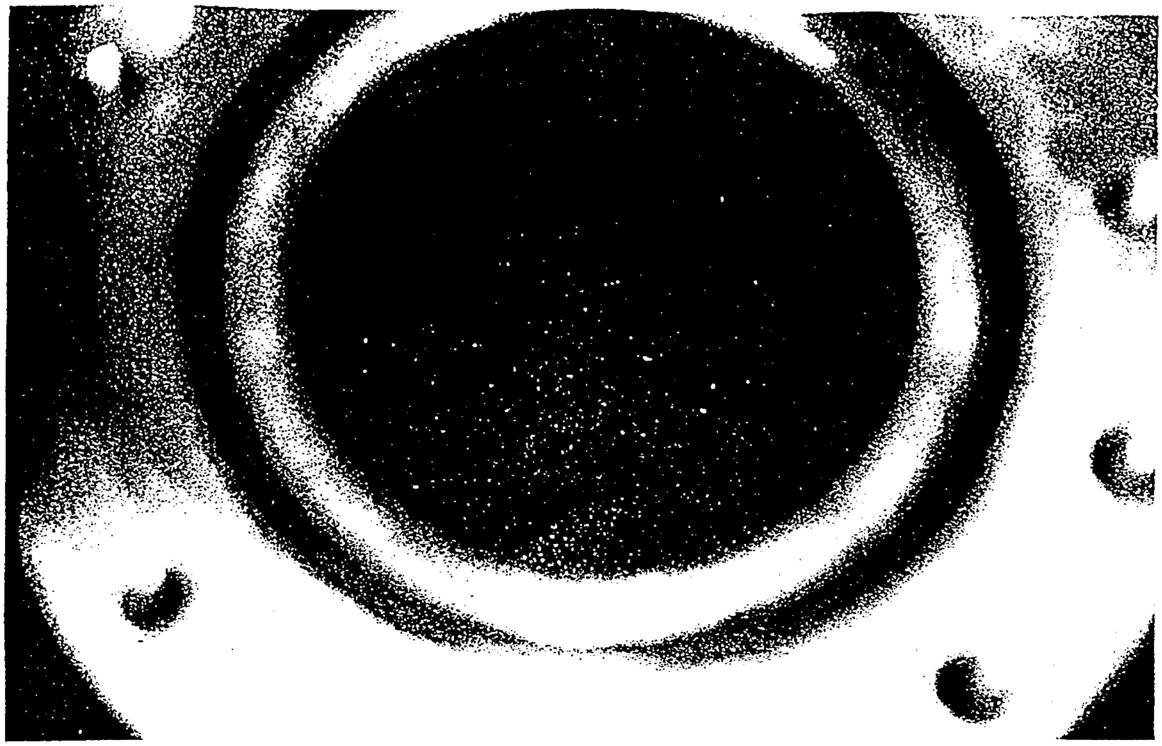


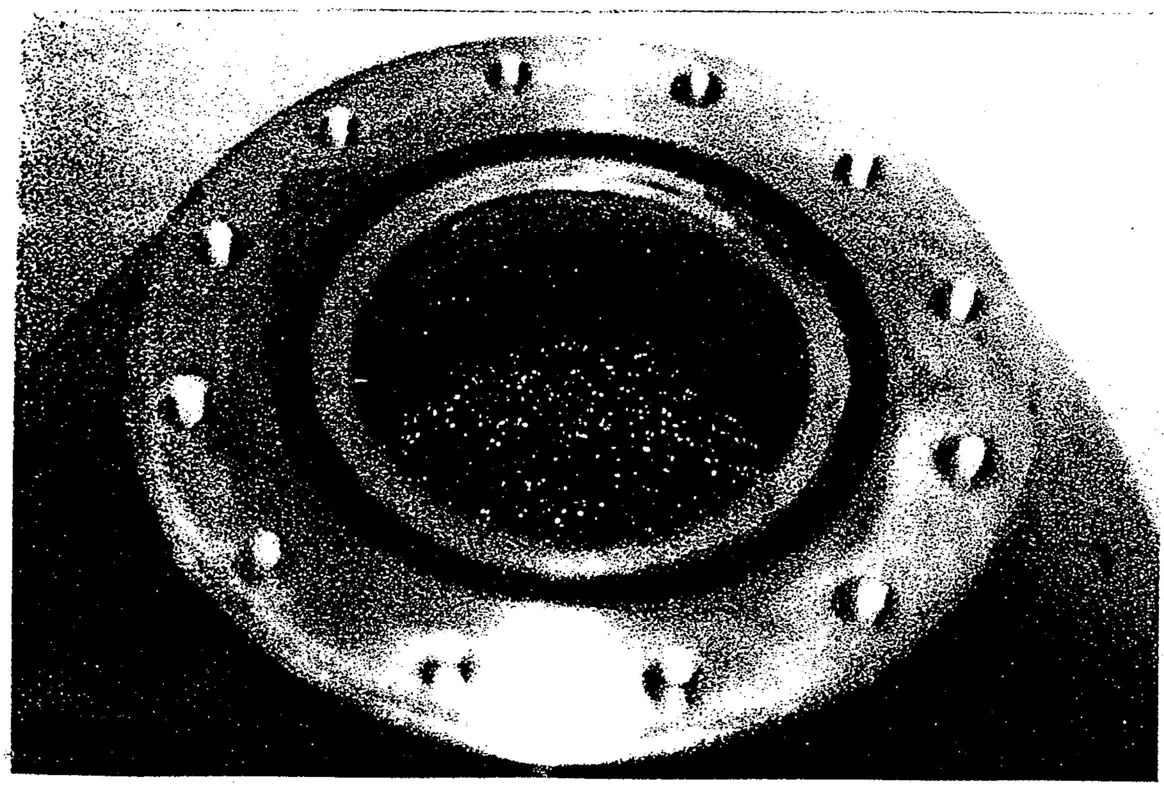


Upper Left - Drum in 1 kg shot tank.

Upper Right - Top view of calorimeter bomb suspended in drum.

Lower Left - Instrumentation and download computer.





Two views post oxygen experiment.

Appendix 5

Details On Charges, Etc.

DSWA-1 (Nitrogen Experiment)

TNT Total Weight 25.0041 g

LX10 Weight 1.6134 g

HE Tape Weight 2.05 g

Shot fired in 30.0 psi (abs.) nitrogen

Transducer #1 - ser. no. 11231

Transducer #2 - ser. no. 11225

DSWA-2 (Oxygen Experiment)

TNT Total Weight 24.9789 g

LX10 Weight 1.6089 g

Shot fired in 37.9 psi (abs.) oxygen = 2.578 atmospheres

Transducer #1- ser. no. 11224

Transducer #2- ser. no. 11223

Measured recess distance of transducer #1 (11224) = .074"

Measured recess distance of transducer #2 (11223) = .082"

Appendix 6

PCB PIEZOTRONICS INC.

CALIBRATION CERTIFICATE

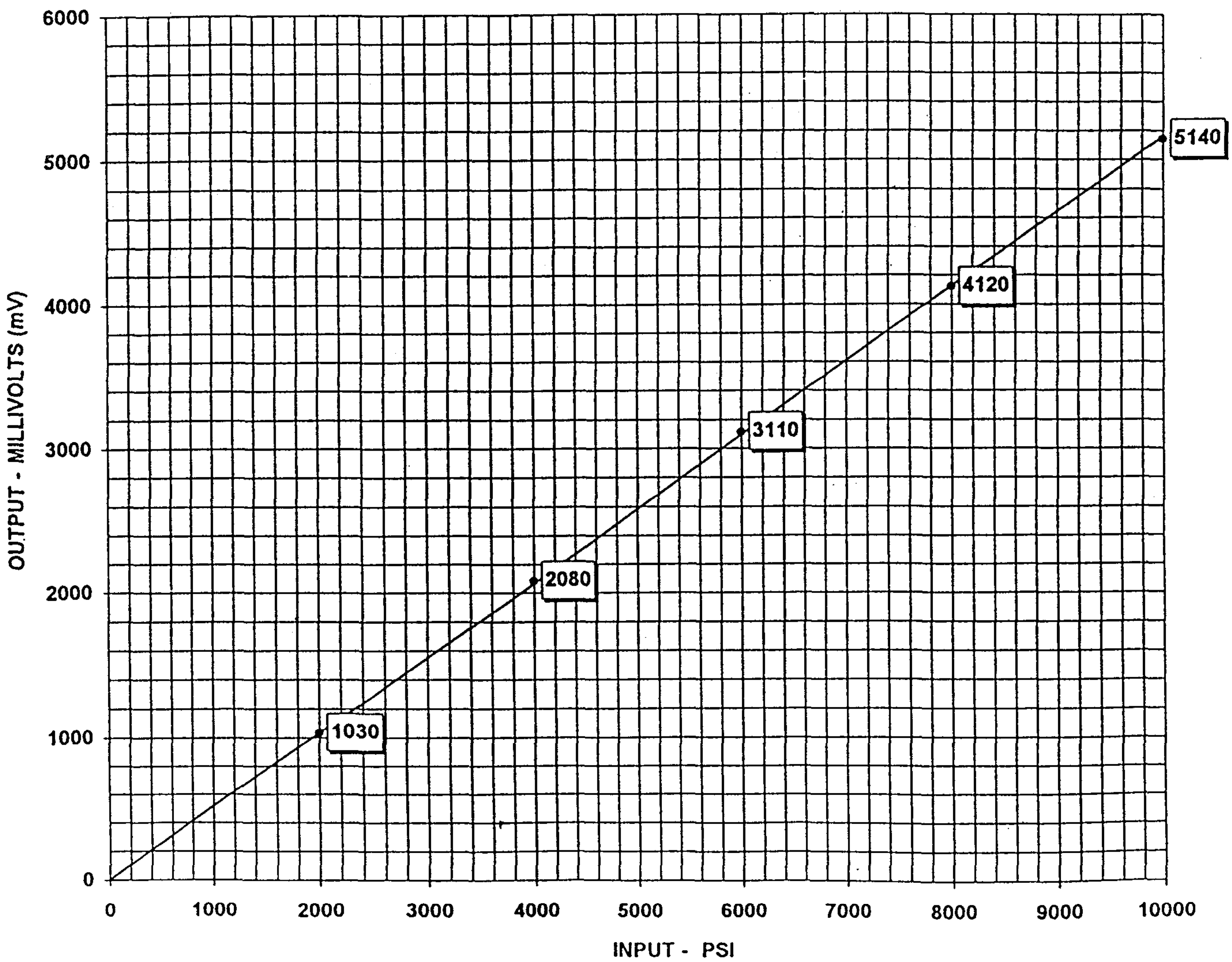
Model: 102A03
Serial #: 11231
Description: Pressure Sensor
Type: ICP

Sensitivity: 0.515 mV/PSI
Linearity: 0.35% FS

Date: 8/26/98
By: Tom Johnston, Cal. Tech. TJ
Station: Dead Weight #3

Cert #: 13767

Notes:
1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
3 This certificate may not be reproduced, except in full, without written approval.



PCB PIEZOTRONICS, INC.
3425 Walden Avenue, Depew NY 14043
Tel: 716-684-0001 Fax: 716-684-0987
Email: sales@pcb.com Web: www.pcb.com

PCB PIEZOTRONICS INC.

CALIBRATION CERTIFICATE

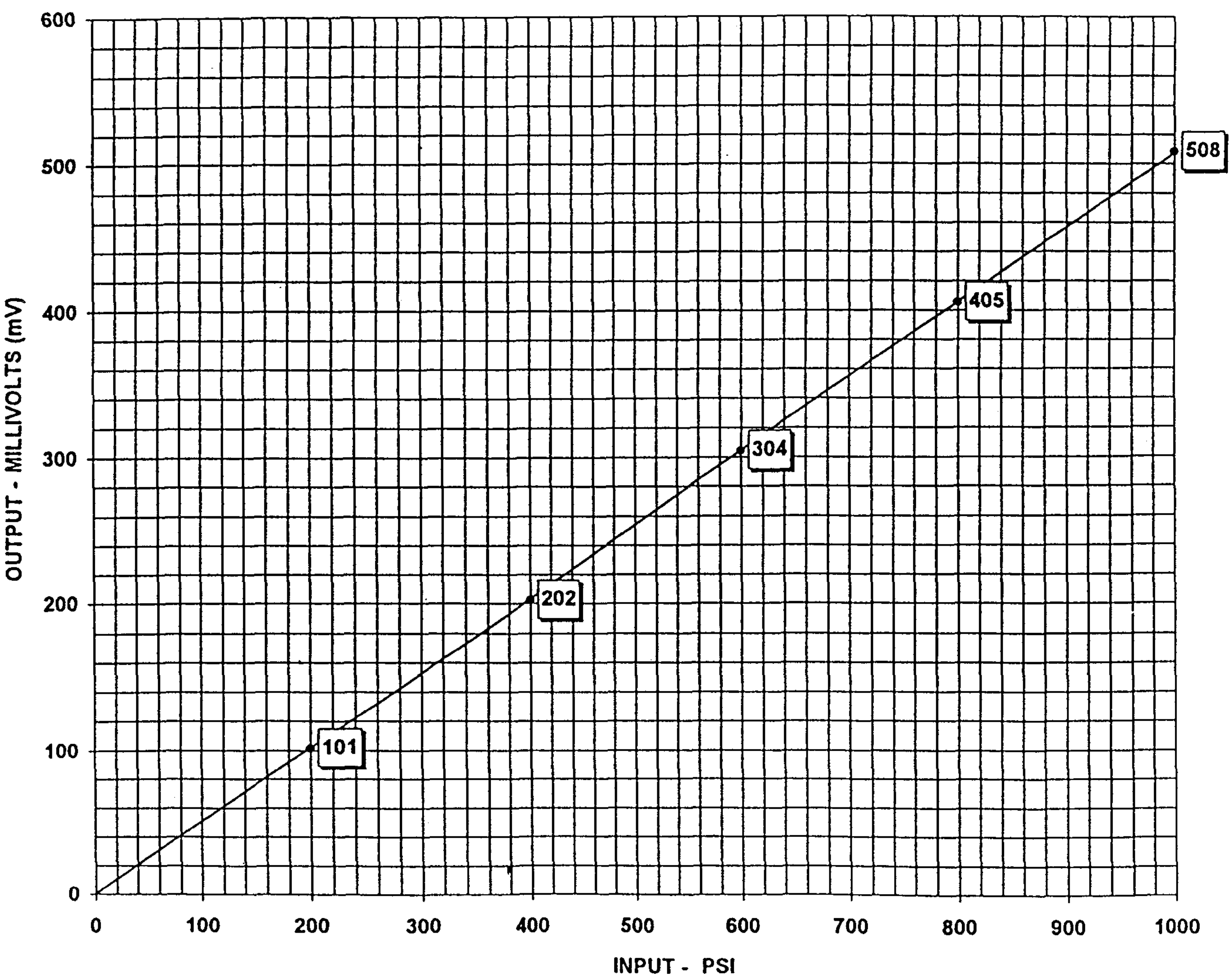
Model: 102A03
Serial #: 11231
Description: Pressure Sensor
Type: ICP

Sensitivity: 0.507 mV/PSI
Linearity: 0.2% FS

Date: 8/26/98
By: Tom Johnston, Cal. Tech. TJ
Station: Dead Weight #3

Cert #: 13769

Notes:
1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
3 This certificate may not be reproduced, except in full, without written approval.



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PCB PIEZOTRONICS INC

CALIBRATION CERTIFICATE

Model:	102A03	**Date:**	8/26/98
Serial #:	11225	**By:**	Tom Johnston, Cal. Tech. TQ
Description:	Pressure Sensor	**Station:**	Dead Weight #3
Type:	ICP		
Sensitivity:	0.488 mV/PSI		
Linearity:	0.32% FS		
		Cert #:	13770

Notes:

1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.

2 NIST traceability through project # 822/255136-95

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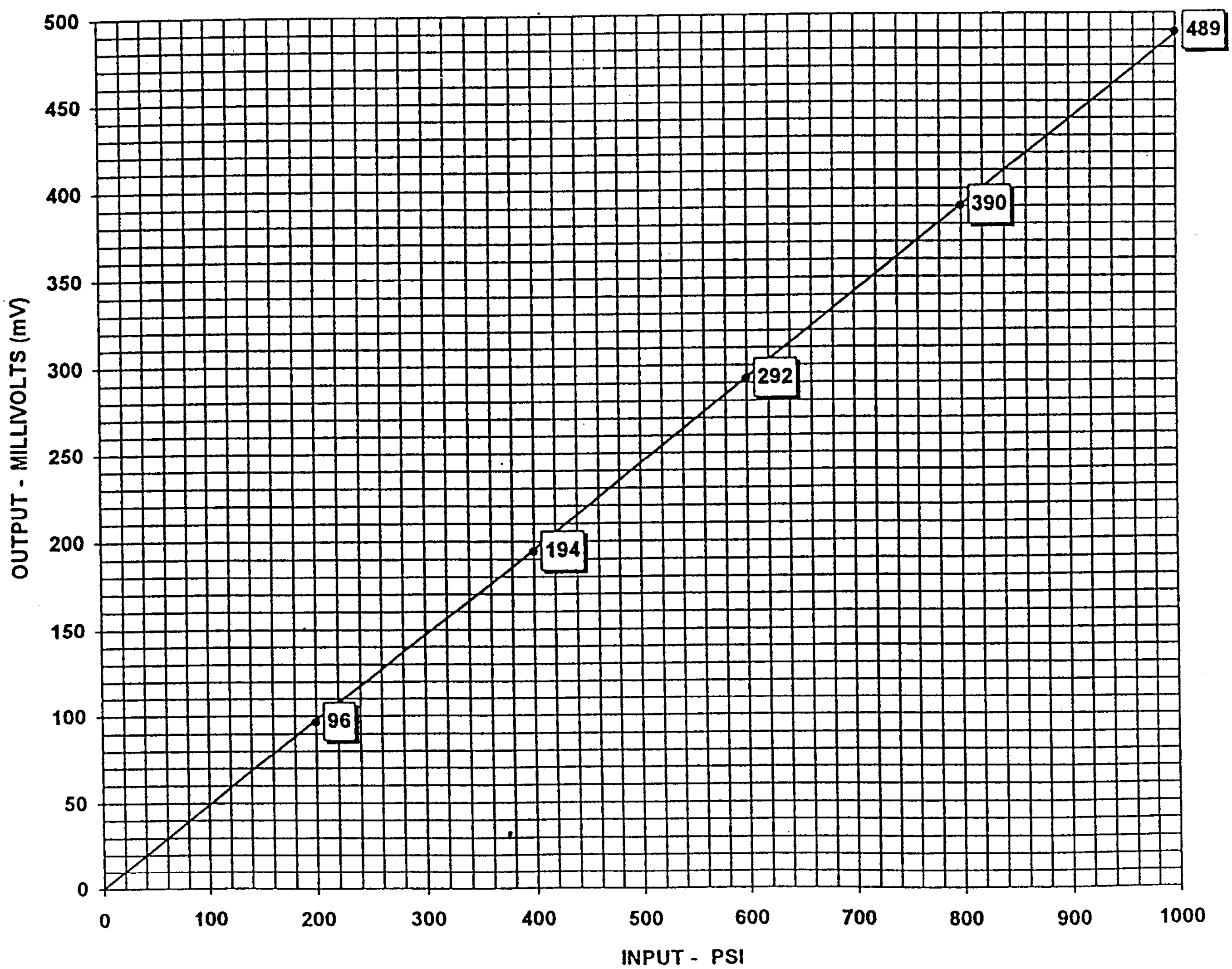

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PCB PIEZOTRONICS INC

CALIBRATION CERTIFICATE

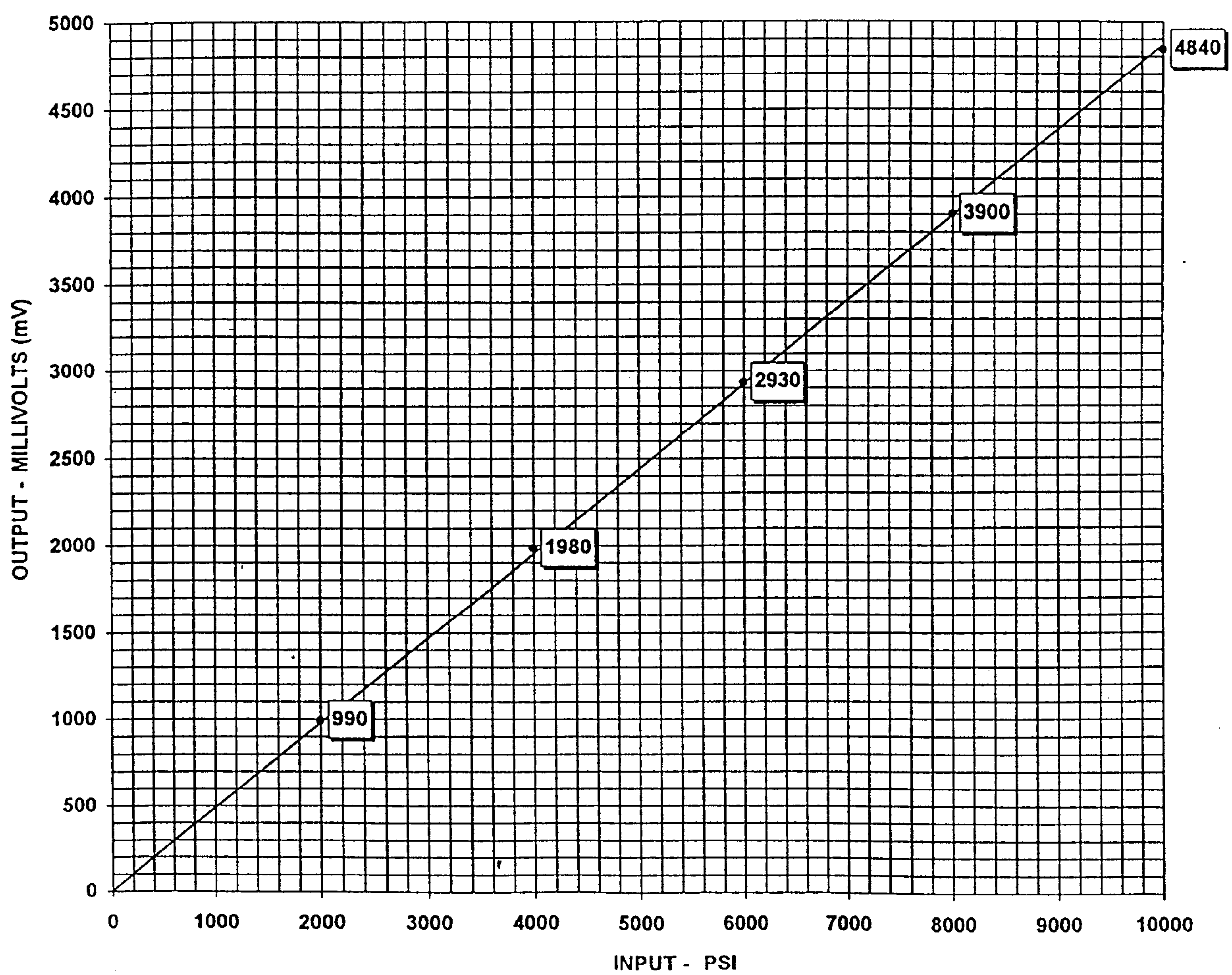
Model: 102A03
Serial #: 11225
Description: Pressure Sensor
Type: ICP

Sensitivity: 0.487 mV/PSI
Linearity: 0.68% FS

Date: 8/26/98
By: Tom Johnston, Cal. Tech. TJ
Station: Dead Weight #3

Cert #: 13766

Notes:
1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
3 This certificate may not be reproduced, except in full, without written approval.



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CALIBRATION CERTIFICATE

Model:	102A03	**Date:**	8/26/98
Serial #:	11224	**By:**	Tom Johnston, Cal. Tech. TJ
Description:	Pressure Sensor	**Station:**	Dead Weight #3
Type:	ICP		
Sensitivity:	0.514 mV/PSI		
Linearity:	0.5% FS		
		Cert #:	13765

Notes:

1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
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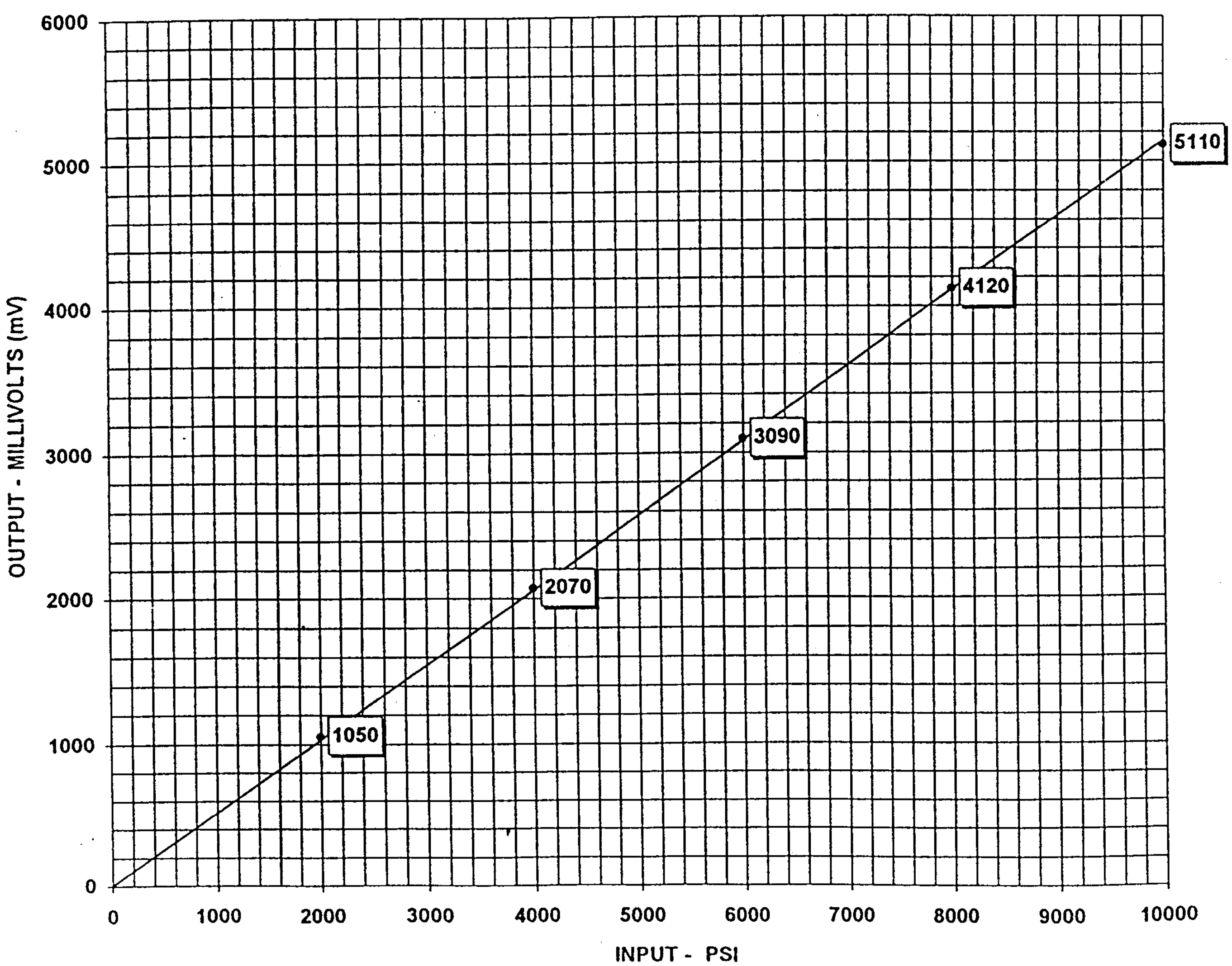

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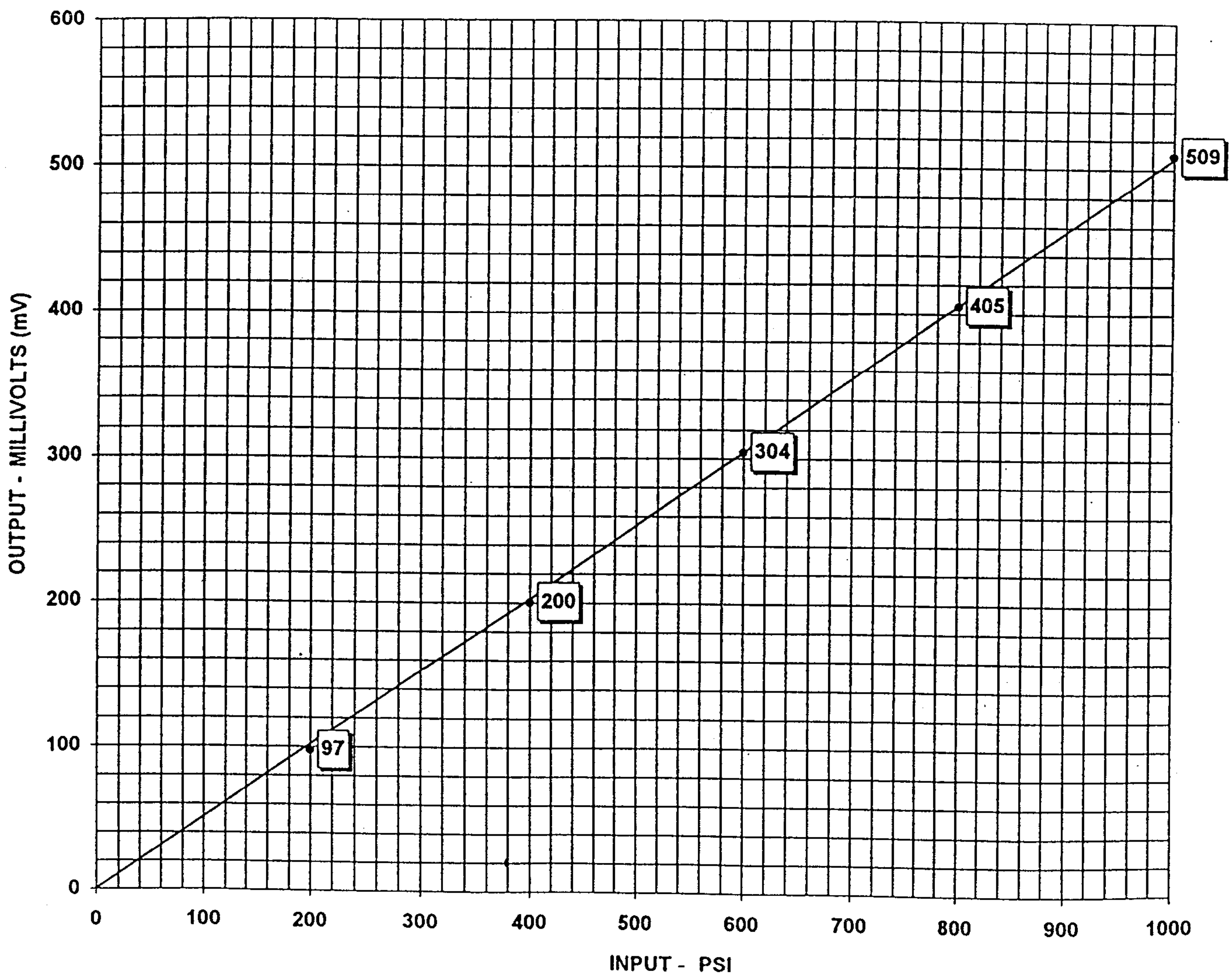
PCB PIEZOTRONICS INC

CALIBRATION CERTIFICATE

Model:	102A03	**Date:**	8/26/98
Serial #:	11224	**By:**	Tom Johnston, Cal. Tech.
Description:	Pressure Sensor	**Station:**	Dead Weight #3
Type:	ICP		
Sensitivity:	0.507 mV/PSI		
Linearity:	0.86% FS		
		Cert #:	13764

Notes:

1. Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2. NIST traceability through project # 822/255136-95
3. This certificate may not be reproduced, except in full, without written approval.



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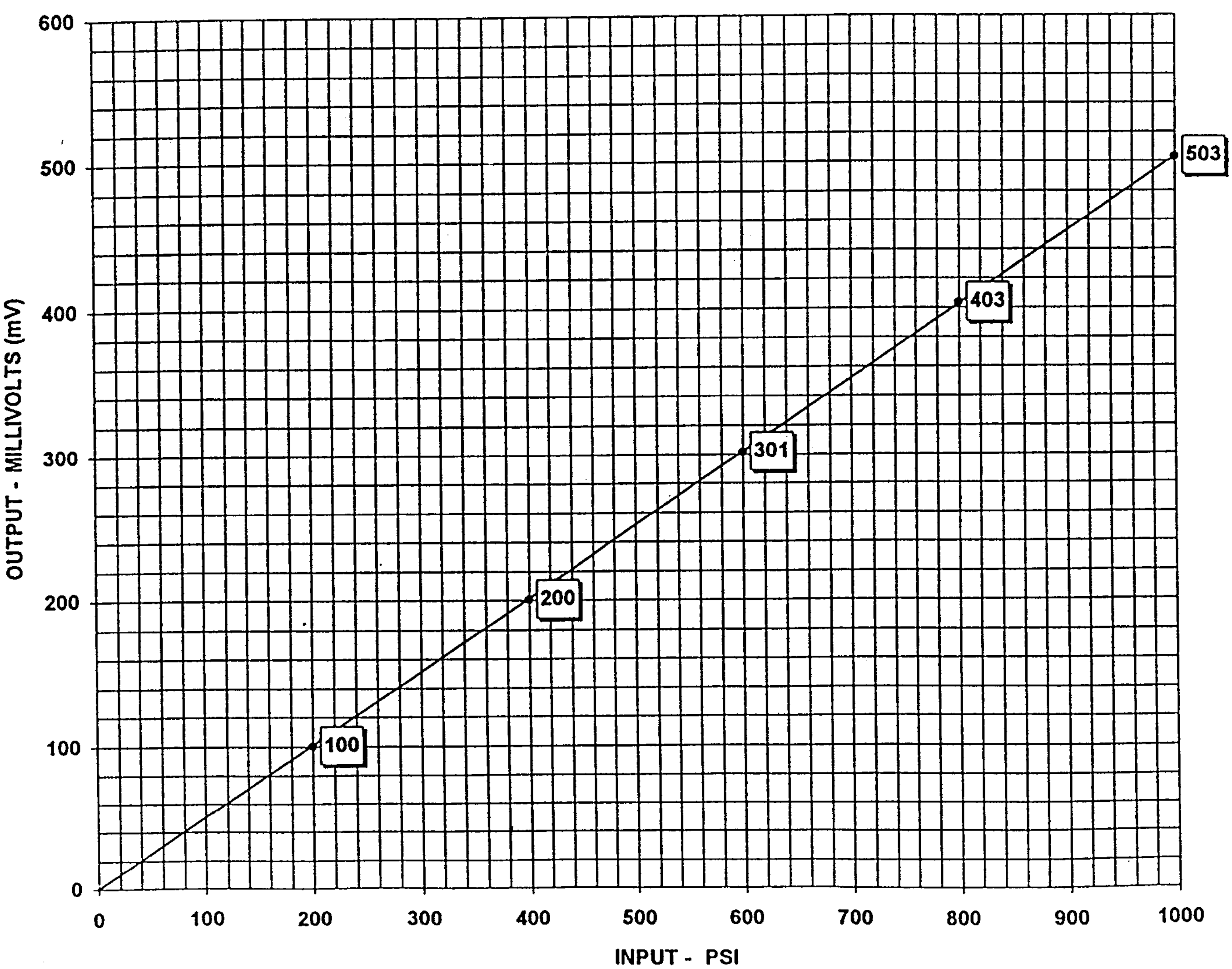
CALIBRATION CERTIFICATE

Model:	102A03	**Date:**	8/26/98
Serial #:	11223	**By:**	Tom Johnston, Cal. Tech. TJ
Description:	Pressure Sensor	**Station:**	Dead Weight #3
Type:	ICP		
Sensitivity:	0.503 mV/PSI		
Linearity:	0.22% FS		
		Cert #:	13763

Notes:

1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
3 This certificate may not be reproduced, except in full, without written approval.



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CALIBRATION CERTIFICATE

Model:	102A03		
Serial #:	11223	**Date:**	8/26/98
Description:	Pressure Sensor	**By:**	Tom Johnston, Cal. Tech. TJ
Type:	ICP	**Station:**	Dead Weight #3
Sensitivity:	0.495 mV/PSI		
Linearity:	0.84% FS		
		Cert #:	13761

Notes:

1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
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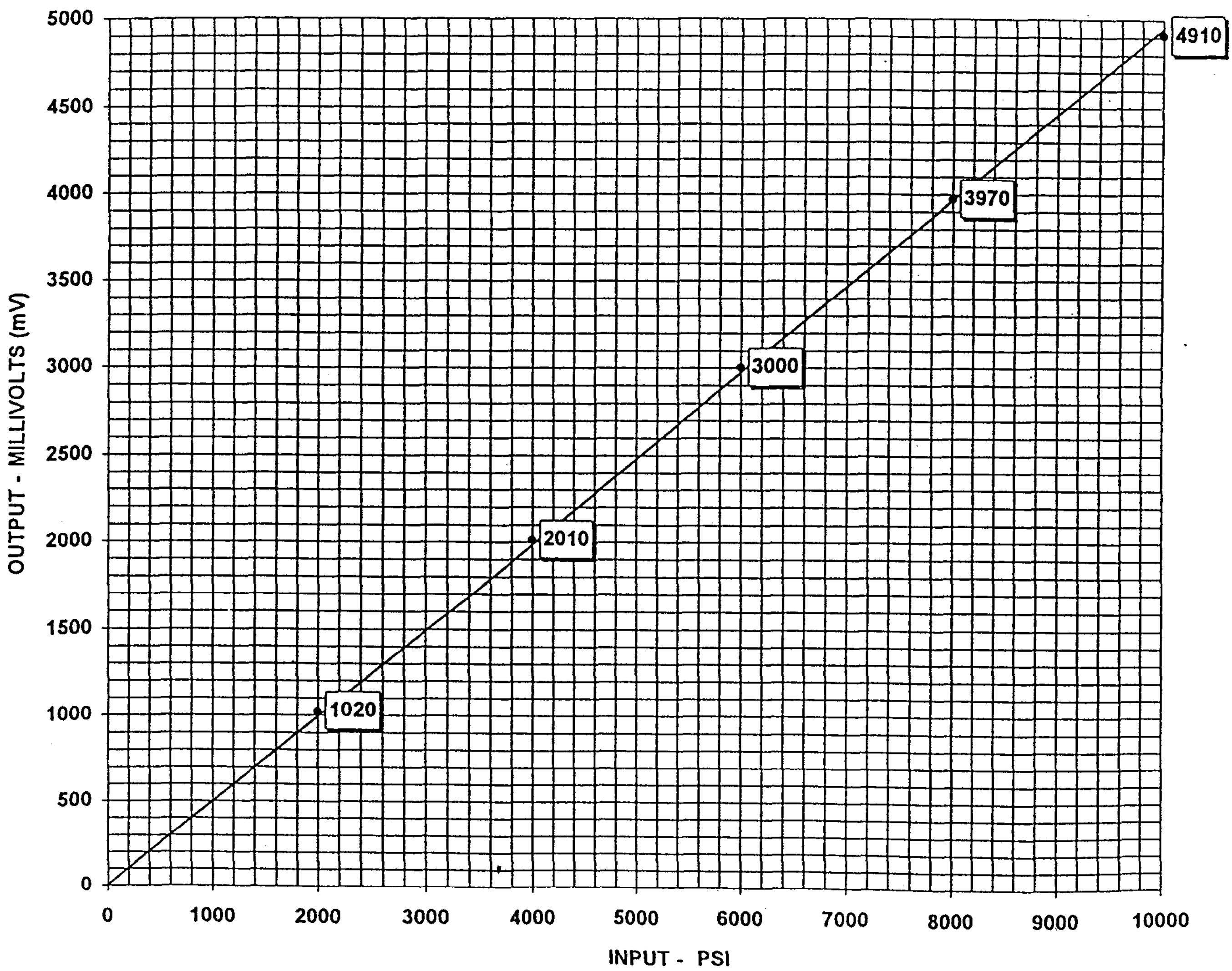

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POST TEST RECALIBRATIONS

(Following replacement of diaphragms)

PCB PIEZOTRONICS INC

CALIBRATION CERTIFICATE

Model:	102A03				
Serial #:	11231	Nat'l Freq:	500 kHz	Date:	4/27/98
Description:	Pressure Sensor			By:	Jonathan Molnar, Cal. Tech.
Type:	ICP			Station:	Dead Weight #1
Sensitivity:	0.509 mV/PSI				
Linearity:	0.18% FS				
				Cert #:	3409

Notes:

1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
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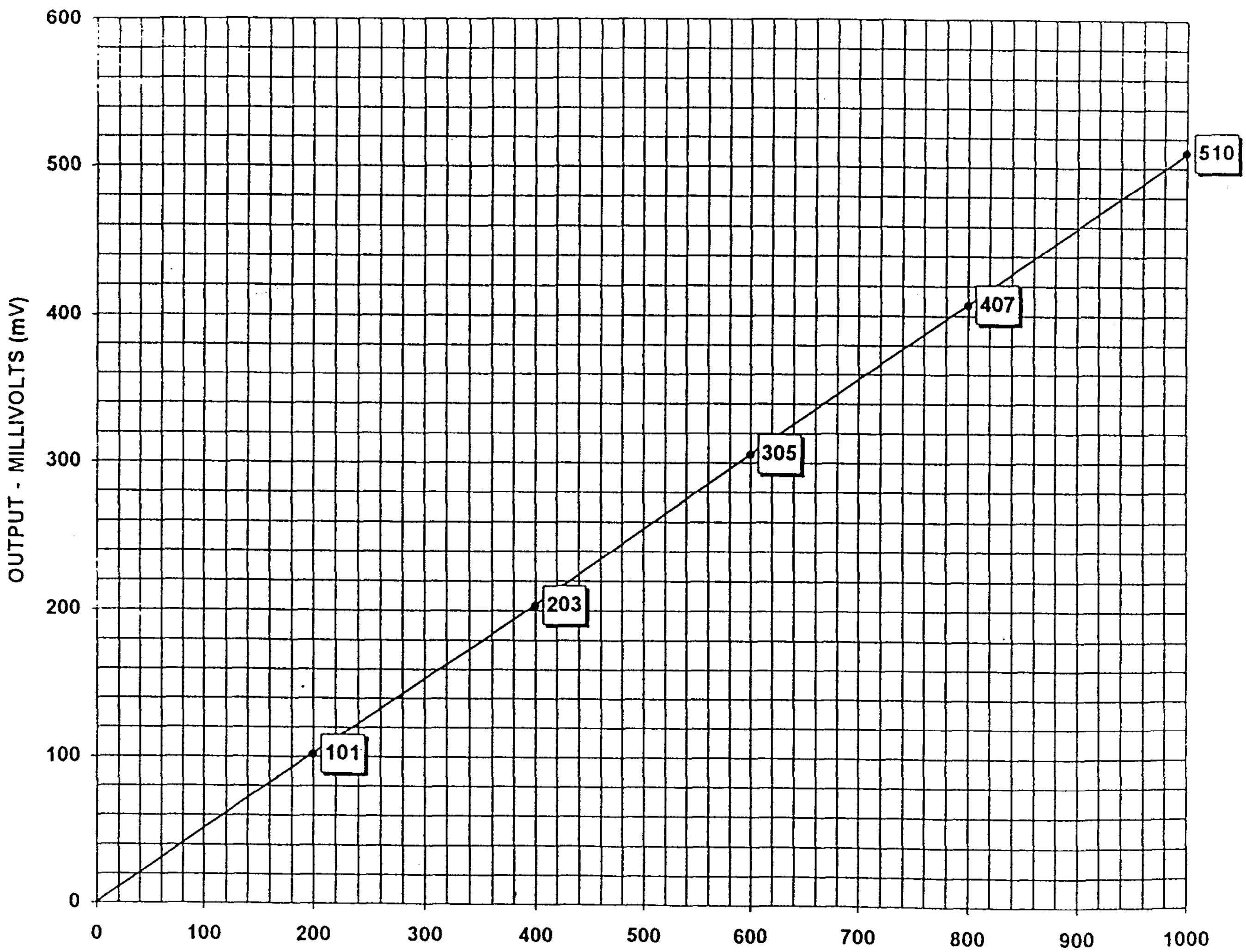

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PCB PIEZOTRONICS INC

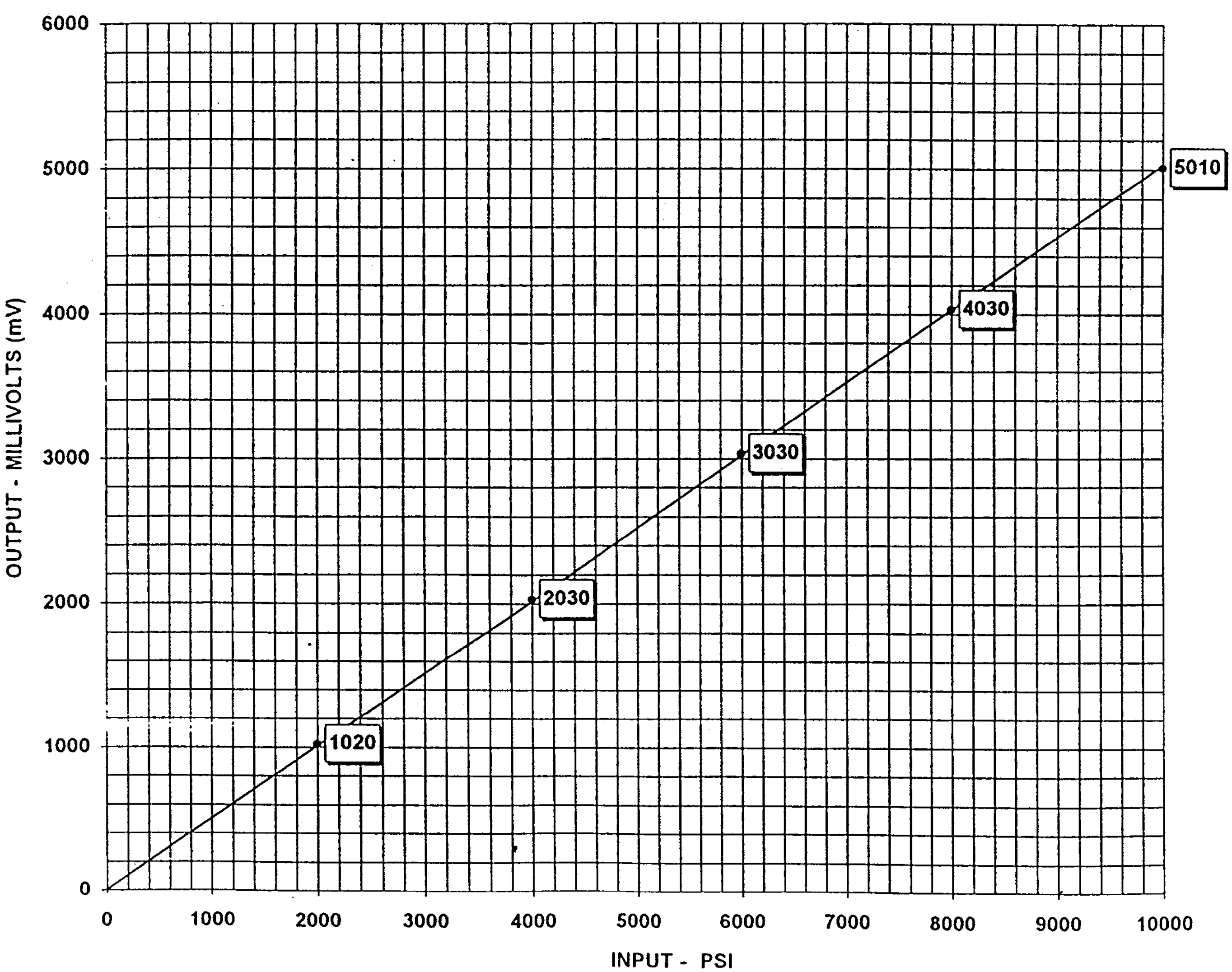
CALIBRATION CERTIFICATE

Model:	102A03				
Serial #:	11231	**Nat'l Freq:**	500 kHz	**Date:**	4/27/98
Description:	Pressure Sensor			**By:**	Jonathan Molnar, Cal. Tech.
Type:	ICP			**Station:**	Dead Weight #1

Sensitivity: 0.503 mV/PSI
Linearity: 0.42% FS

Cert #: 3410

Notes:
1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
3 This certificate may not be reproduced, except in full, without written approval.



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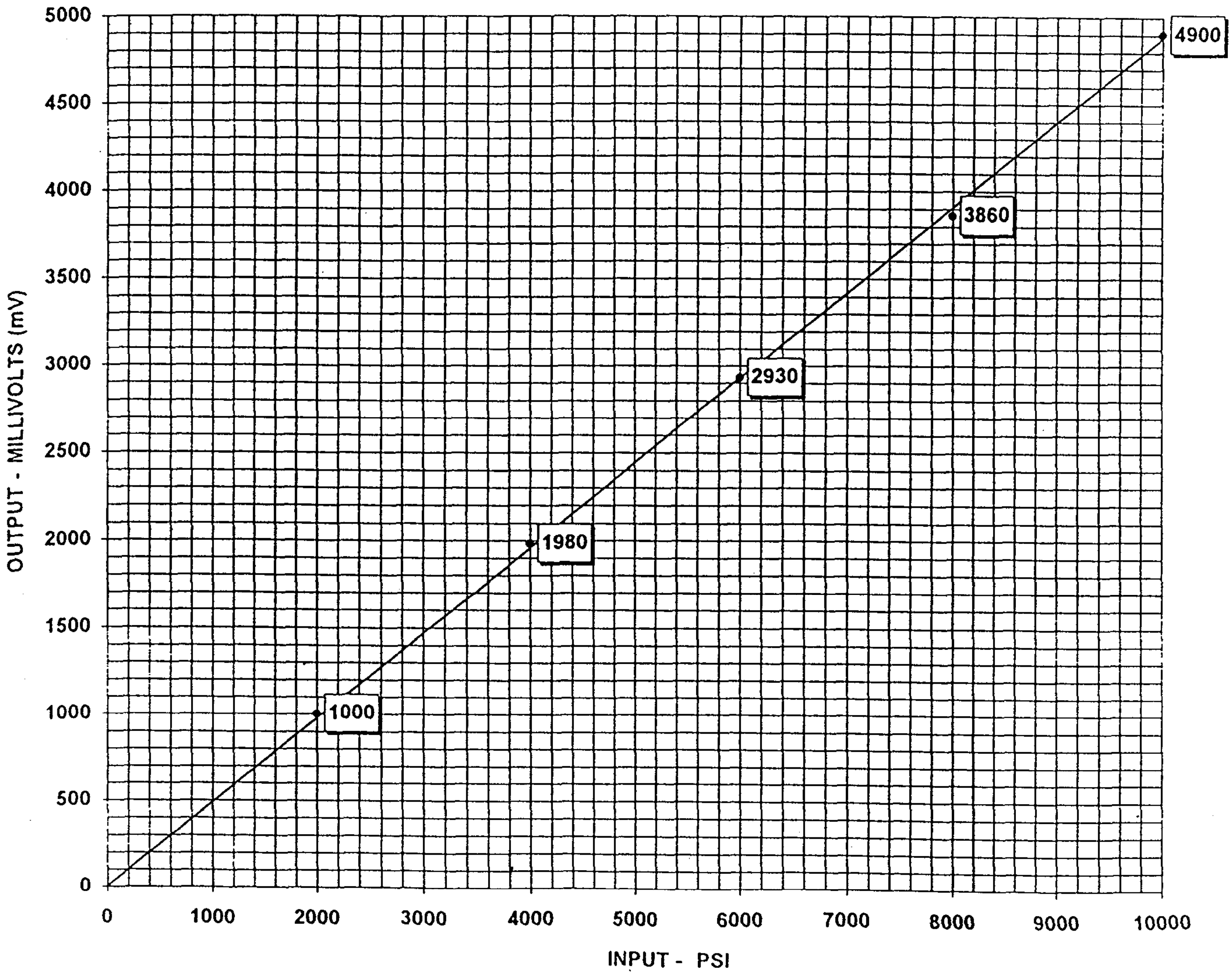
PCB PIEZOTRONICS INC

CALIBRATION CERTIFICATE

Model:	102A03				
Serial #:	11225	**Nat'l Freq:**	500 kHz	**Date:**	4/27/98
Description:	Pressure Sensor			**By:**	Jonathan Molnar, Cal. Tech.
Type:	ICP			**Station:**	Dead Weight #1
Sensitivity:	0.488 mV/PSI				
Linearity:	0.92% FS				
				Cert #:	3408

Notes:

1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
3 This certificate may not be reproduced, except in full, without written approval.



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CALIBRATION CERTIFICATE

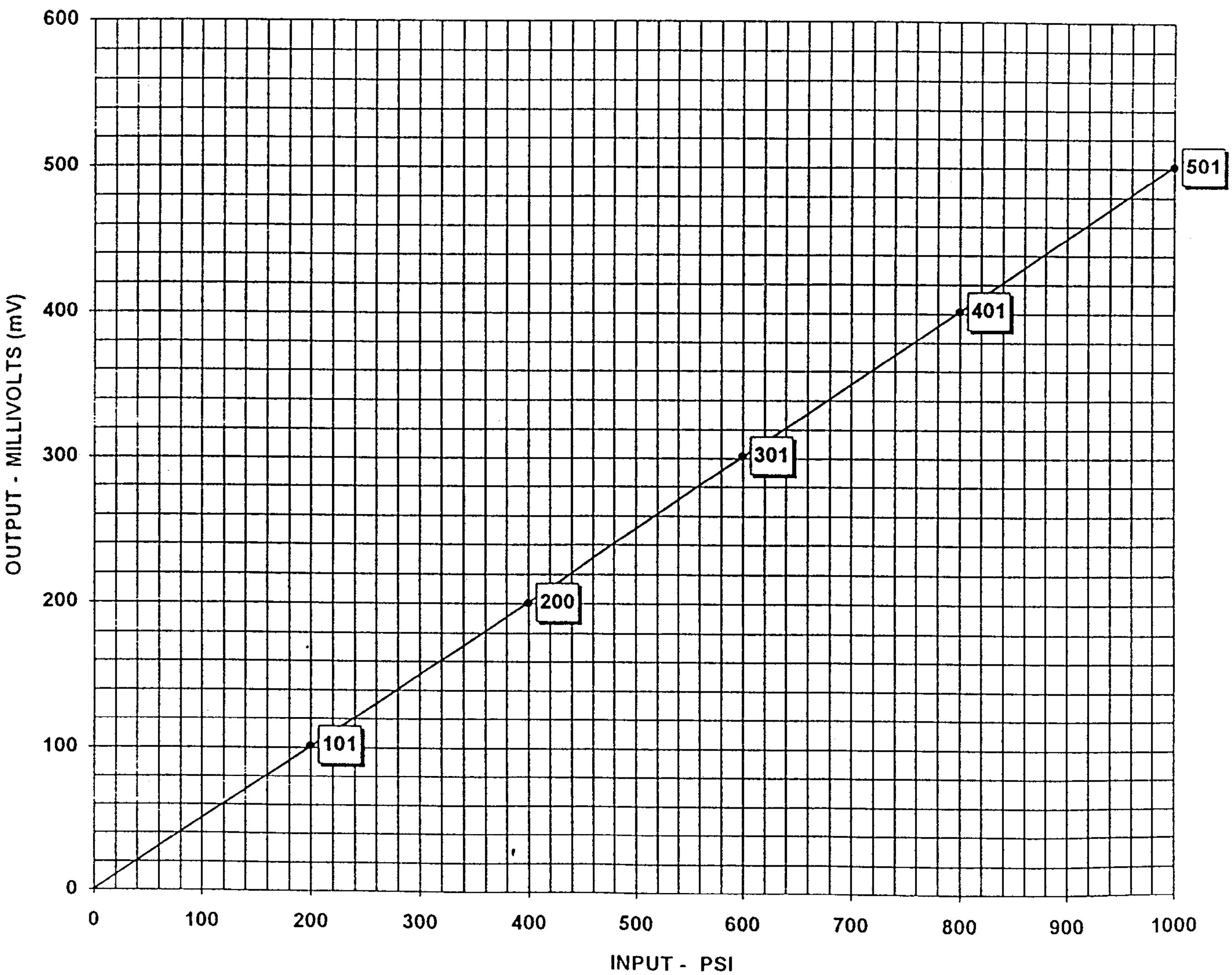
Model:	102A03				
Serial #:	11225	Nat'l Freq:	500 kHz	Date:	4/27/98
Description:	Pressure Sensor			By:	Jonathan Molnar, Cal. Tech.
Type:	ICP			Station:	Dead Weight #1

Sensitivity: 0.501 mV/PSI
Linearity: 0.15% FS

Cert #: 3407

Notes:

1. Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2. NIST traceability through project # 822/255136-95
3. This certificate may not be reproduced, except in full, without written approval.



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PCB PIEZOTRONICS INC

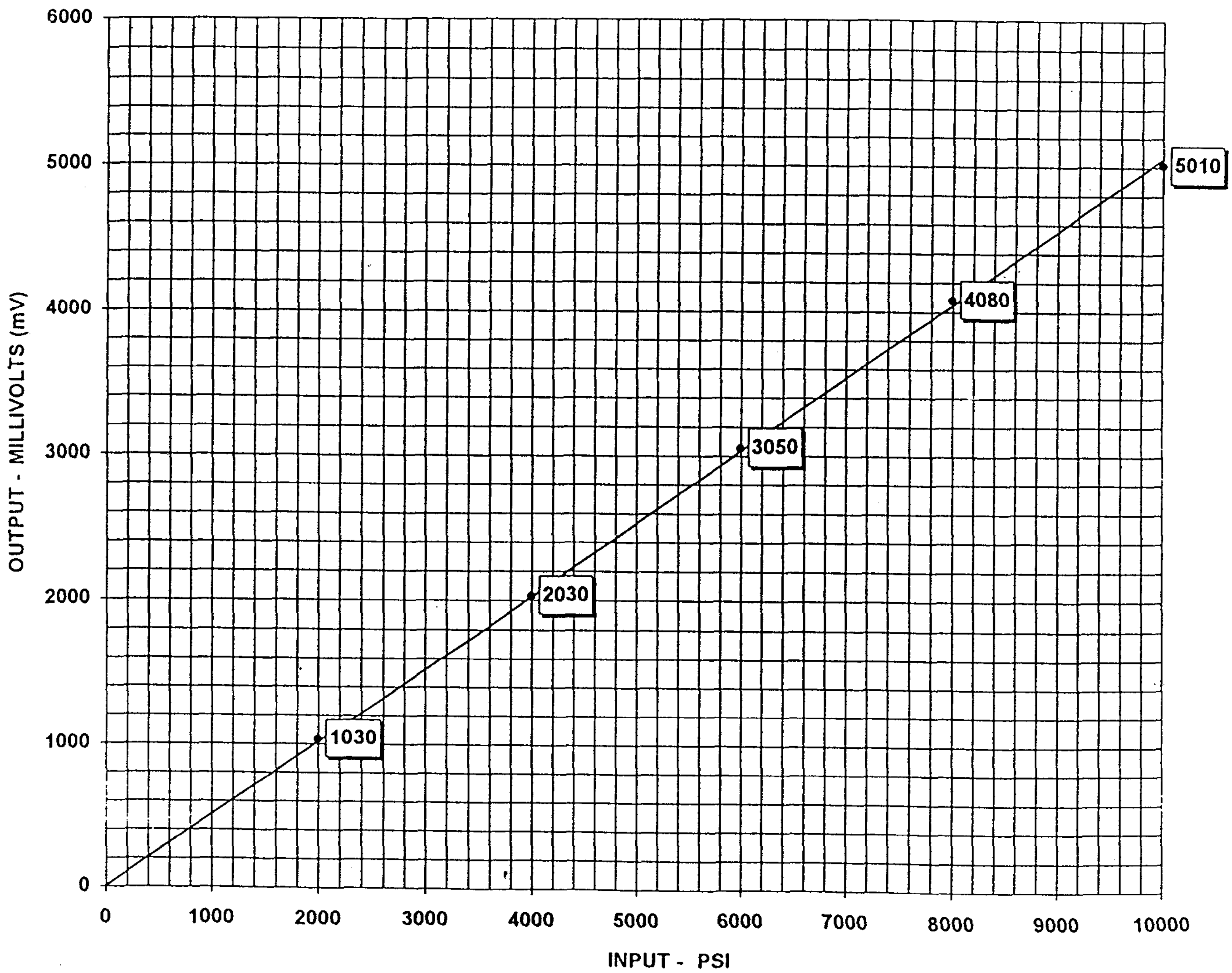
CALIBRATION CERTIFICATE

Model:	102A03				
Serial #:	11224	**Nat'l Freq:**	500 kHz	**Date:**	4/27/98
Description:	Pressure Sensor			**By:**	Jonathan Molnar, Cal. Tech.
Type:	ICP			**Station:**	Dead Weight #1

Sensitivity: 0.506 mV/PSI
Linearity: 0.9% FS

Cert #: 3406

Notes:
1. Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2. NIST traceability through project # 822/255136-95
3. This certificate may not be reproduced, except in full, without written approval.



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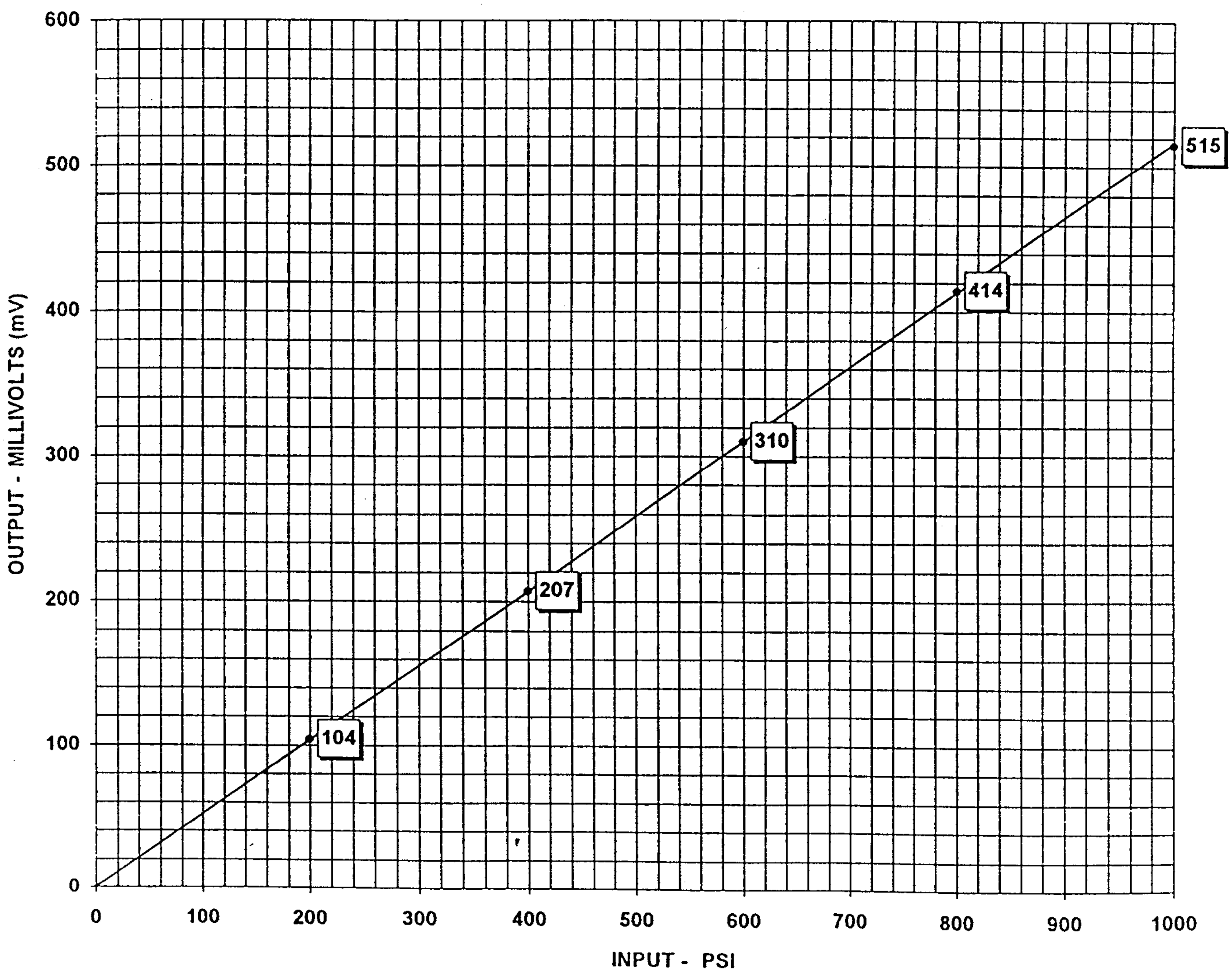
PCB PIEZOTRONICS INC

CALIBRATION CERTIFICATE

Model:	102A03				
Serial #:	11224	Nat'l Freq:	500 kHz	Date:	4/27/98
Description:	Pressure Sensor			By:	Jonathan Molnar, Cal. Tech.
Type:	ICP			Station:	Dead Weight #1
Sensitivity:	0.516 mV/PSI				
Linearity:	0.25% FS				
				Cert #:	3405

Notes:

1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
3 This certificate may not be reproduced, except in full, without written approval.



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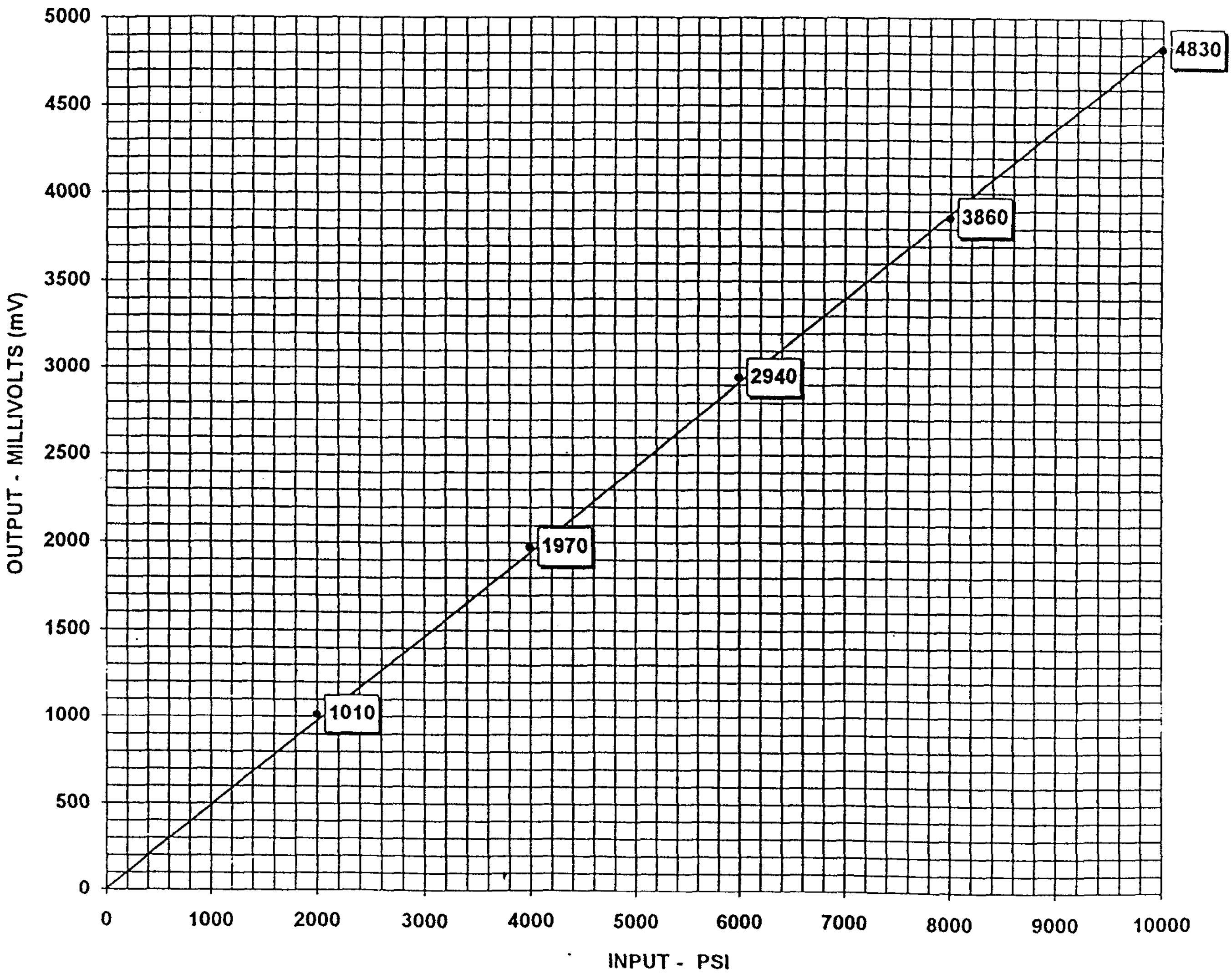
PCB PIEZOTRONICS INC

CALIBRATION CERTIFICATE

Model:	102A03				
Serial #:	11223	**Nat'l Freq:**	525 kHz	**Date:**	4/27/98
Description:	Pressure Sensor			**By:**	Jonathan Molnar, Cal. Tech.
Type:	ICP			**Station:**	Dead Weight #1
Sensitivity:	0.485 mV/PSI				
Linearity:	0.82% FS				
				Cert #:	3404

Notes:

1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
3 This certificate may not be reproduced, except in full, without written approval.



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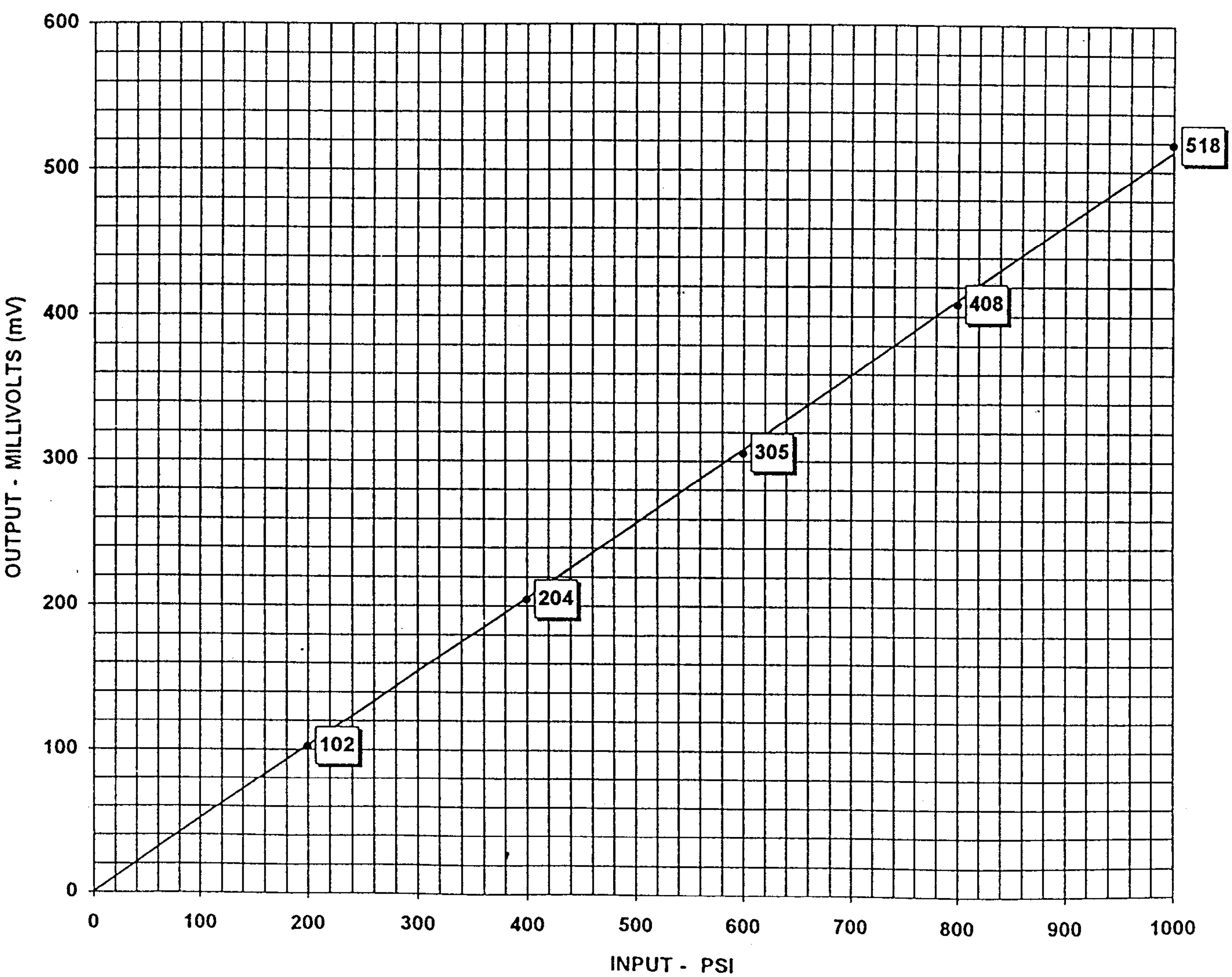
CALIBRATION CERTIFICATE

Model:	102A03				
Serial #:	11223	**Nat'l Freq:**	525 kHz	**Date:**	4/27/98
Description:	Pressure Sensor			**By:**	Jonathan Molnar, Cal. Tech.
Type:	ICP			**Station:**	Dead Weight #1
Sensitivity:	0.513 mV/PSI				
Linearity:	0.9% FS				
				Cert #:	3403

Notes:

1 Calibration is traceable to NIST and complies with ISO 10012-1 and former MIL-STD-45662A.
2 NIST traceability through project # 822/255136-95
3 This certificate may not be reproduced, except in full, without written approval.



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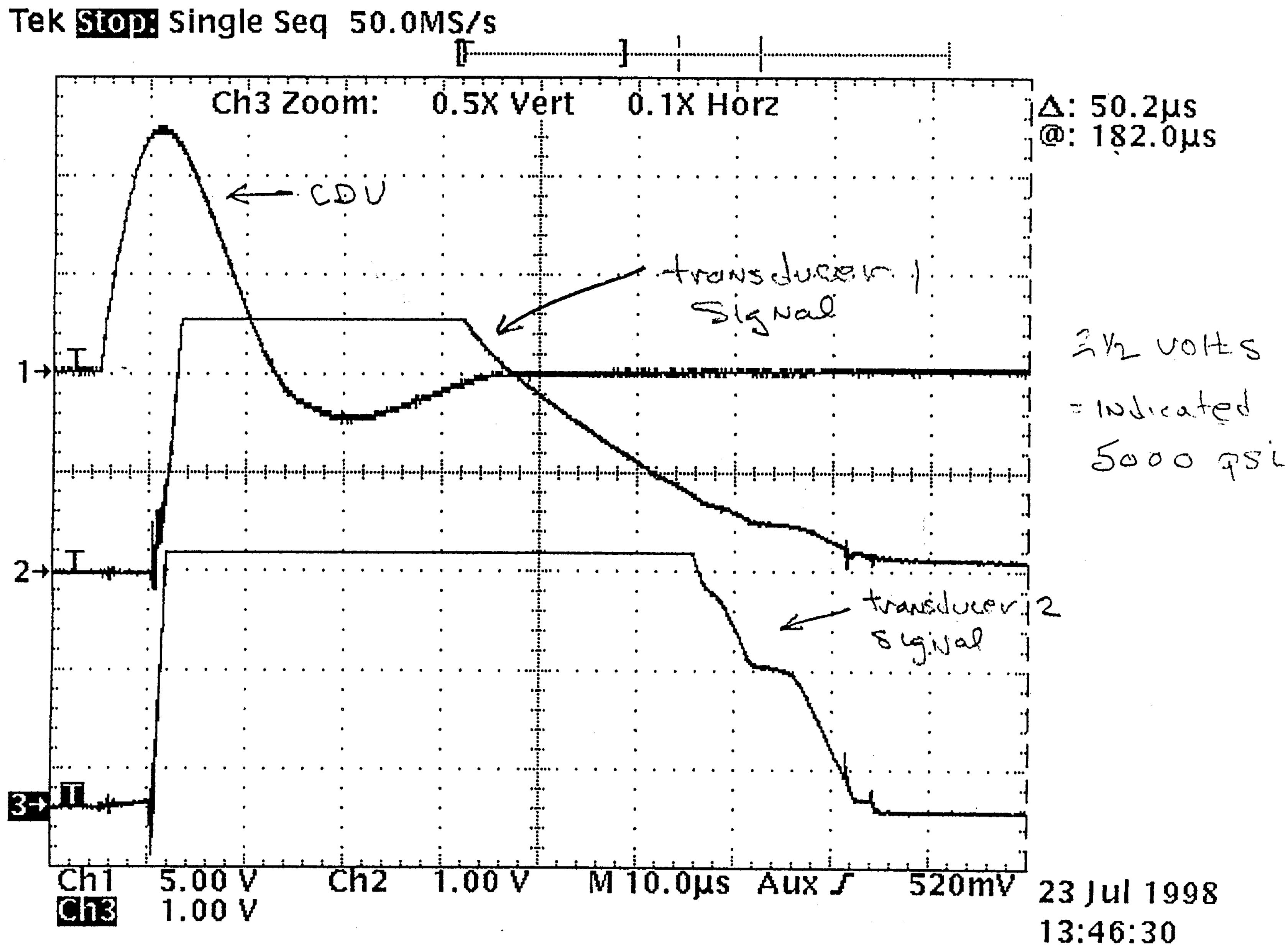
Appendix 7



Bridgewire Calibration